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A SUMMARY OF SPACECRAFT LOADS DATA FROM FOUR TITAN CENTAUR LAUNCH VEHICLE FLIGHTS

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16. Abstract

The payloads carried by the first four Titan Centaur Launch Vehicle flights were a Viking Spacecraft Dynamic Simulator, the Helios-A Spacecraft and the two Viking Spacecraft. Dynamic loads data were gathered by the NASA Viking Project Office from these four flights. This report presents a summarization of these data, makes comparisons with Viking design requirements and makes recommendations on design and test requirements for general spacecraft application.

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A SUMMARY OF SPACECRAFT LOADS DATA FROM FOUR TITAN CENTAUR LAUNCH VEHICLE FLIGHTS

Summary

The objective of this report is to present a summary of dynamics data measurements made on the spacecraft of four Titan Centaur launch vehicles. The data is presented in the six categories of acoustics, vibration, stage zero ignition overpressure, shock spectra of staging transients, oscillations resulting from thruster and structural mode coupling and venting pressures. Flight measurements are shown to be in the general range of predictions with two notable exceptions. The acoustic spectra were not as predicted, the major difference being due to low frequency content of the lift off environment. The notches in the mid-frequency sine test did not appear to provide adequate margin above flight measurements.

1. Introduction

This report has been written with the intent of making available in a convenient summary the Titan Centaur flight dynamics data acquired by the Viking Project Office in application to the Viking Spacecraft. It is hoped that the vibration, acoustic and pressure data presented will be of use in establishing design criteria for future spacecraft.

The Viking Project is the current NASA effort to explore Mars using two unmanned spacecraft during the 1975-1976 opportunity. The project is managed by the Viking Project Office and NASA's Langley Research Center. The two spacecraft were individually launched on the new Titan III E/Centaur D-1T launch vehicle on August 20 and September 9, 1975. The objective of this Project is to obtain scientific data which will significantly advance the knowledge of the planet Mars by direct measurements in the atmosphere and on the surface. Particular emphasis will be placed on obtaining information concerning biological, chemical, and environmental factors relevant to the existance of life on Mars.

2. Spacecraft Description, Dynamic Environments Overview

The general configuration of the Titan Centaur Launch Vehicle and the spacecraft of the first four launchings are shown in Figures 2.1 and 2.2. The Viking Dynamic Simulator (VDS) was carried on the Proof Flight (TC-1). Helios A was launched by the second Titan Centaur, TC-2. Viking A Spacecraft and Viking B Spacecraft were launched on TC-4 and TC-3 in that order.

The VDS consisted of stainless steel welded constructions representing the mass and center of gravity properties of the Viking Lander Capsule and the Viking Orbiter. These masses were connected by the same configuration of truss adapters as used in the Viking Spacecraft (VS/C) with the net result of very similar low frequency dynamic characteristics. A schematic of the truss adapters is shown in Figure 3-1.

The Helios A was a much smaller spacecraft than Viking and included a fourth stage rocket motor: Delta stage model 3L-20, S/N 2003 (TE-M-364-4). The total weight of the Helios and Delta was 3730 pounds; approximately half the Viking's 7750 pounds. Comparisons of the cantilevered frequencies of the three spacecraft are shown in Table 2.1.

Table 2.1 A Comparison of Modal Frequencies of the Cantilevered Spacecraft

Mode Description	Mode Number and Frequency					
	Viking Spacecraft		Viking Dynamic Simulator		Helios A	
	No.	Hz	No.	Hz	No.	Hz
Bending	1	4.32	1	4.48	1	7.0
	2	4.40	2	4.66	2	7.0
Coupled Bending & Roll	3	6.93	3	6.85	3	15.0
	4	7.03			4	15.0
	5	9.04	4	9.45	5	20.0
	6	9.67	5	9.50		
Longitudinal	13	14.55	6	13.41	6	35.0
	15	15.67	7	13.96		

The Viking spacecraft were much more complex internally than the VDS or the Helios, with several large appended masses. Modes due to these appended masses are consequently interspersed with the overall structural modes.

There are sixteen separate Launch Vehicle events or conditions which went into the makeup of the Viking Spacecraft dynamic environment. (1) Stage 0 Ignition and Lift Off, (2) Mach 1/Max Q Buffet, (3) Forward Bearing Reaction (FBR) Release, (4) Stage I Ignition, (5) Jettison of Stage 0 Solid Rocket Motors (SRM), (6) Longitudinal oscillations characteristic of Stage 1 Burning, (7) Stage 1 Burn Out and Stage 2 Ignition, (8) Shroud Jettison, (9) Stage 2 Burnout, (10) Titan/Centaur Separation, (11) Centaur First Main Engine Start (MES-1), (12) Lateral oscillations characteristic of Centaur Burn, (13) Centaur First Main Engine Cut Off (MECO-1), (14) MES-2, (15) MECO-2 and (16) Spacecraft Separation. (This list does not include Titan Stage 0 Burn Out and Titan Heat Shield jettison both of which result in negligible spacecraft loads).

Figure 2.3 shows the sequence and approximate time from lift off of most of these events. Figures 2.4 and 2.5 show the typical acceleration time history through the powered flight phase of launch flight and the Mach number and dynamic pressure time history for the first 150 seconds of launch flight.

The frequency content of the dynamic environments created by these 16 events goes from steady state inertial loading (zero frequency) to pyro actuated events causing transient vibration in the two to five kilo Hertz range. Division into the four frequency categories shown in Table 2, evolved from considerations of effect of the environment on the spacecraft and of test methods to be used to recreate the effects in the laboratory.

Table 2.2. Frequency Categories of the Viking Spacecraft Dynamic Environments

Frequency Range (Hertz)	Environment	Soure of Data	Impact of Environment	Qualification Test Methods
0 - 30	Booster Transients - Low Frequency	Dynamic Loads Analyses	Design Loads for primary structure	Static test
30 - 200	Booster Transients - Mid Frequency	Empirical Data and Dynamic Loads Analysis	o Design loads for secondary structure o Component test requirements	Sine sweep test
20 - 2000	Acoustic Pressure	Empirical Data	o Component Random Vibration Test o Design conditions for local structure	o Random vibration test o Acoustic test
100 - 10000 High Frequency	Pyro Shock	Empirical Data	Component shock test requirements	o Fire actual pyro in spacecraft o Fire pyro simulation o Shock test (Pendulum & Shaker)

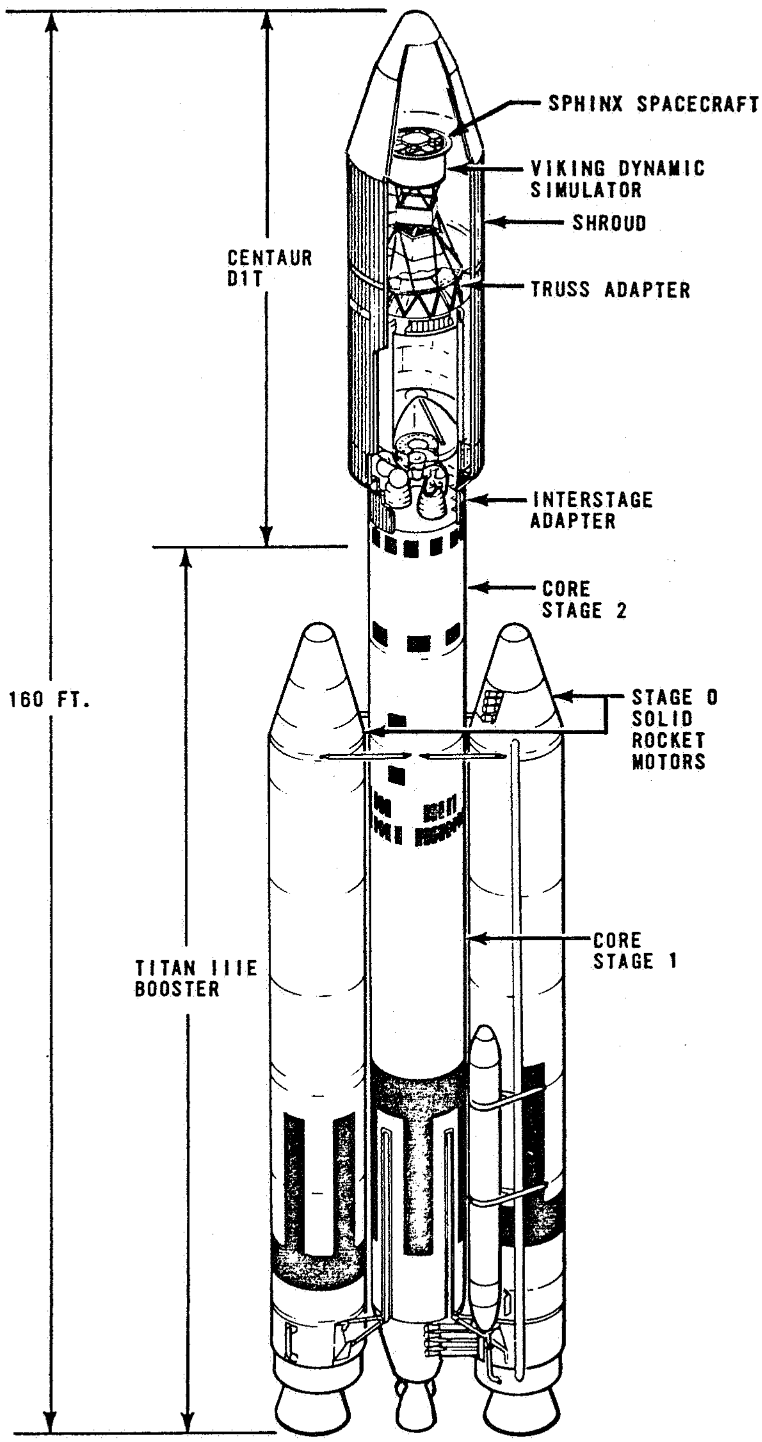
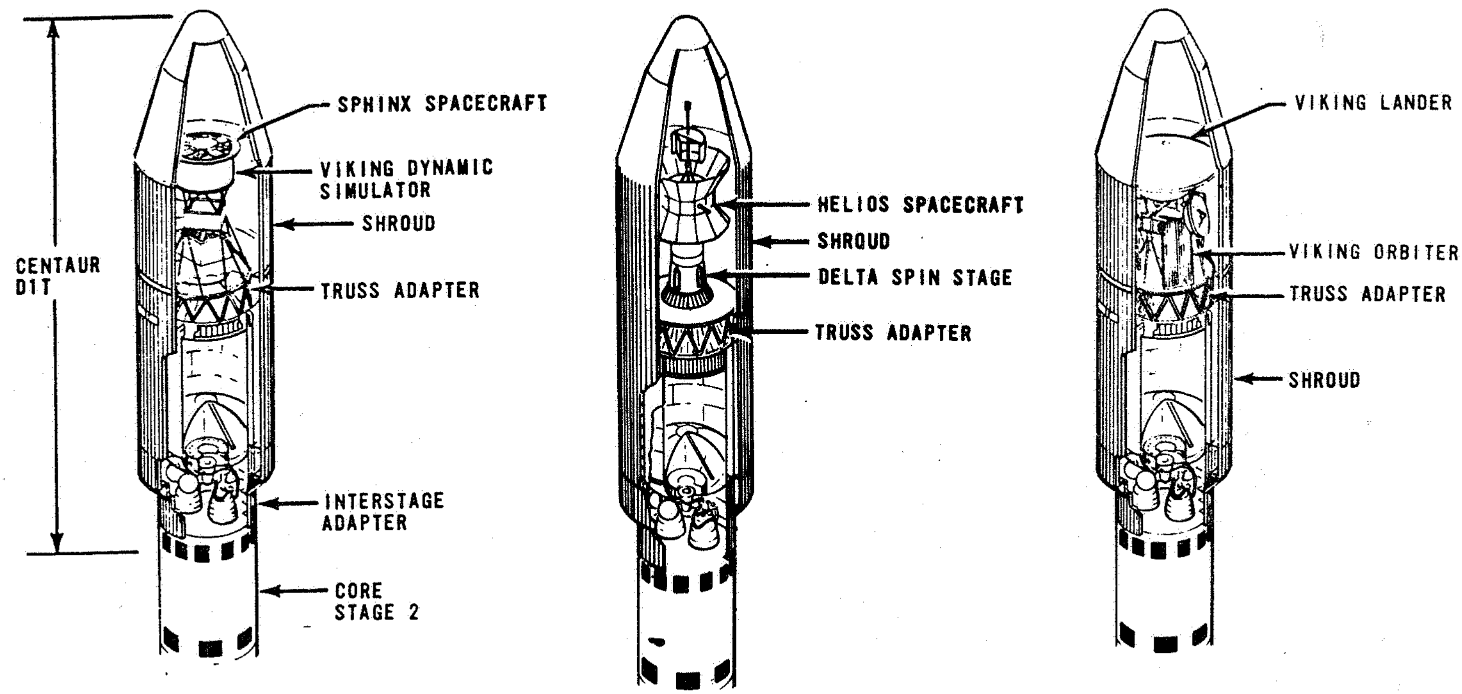
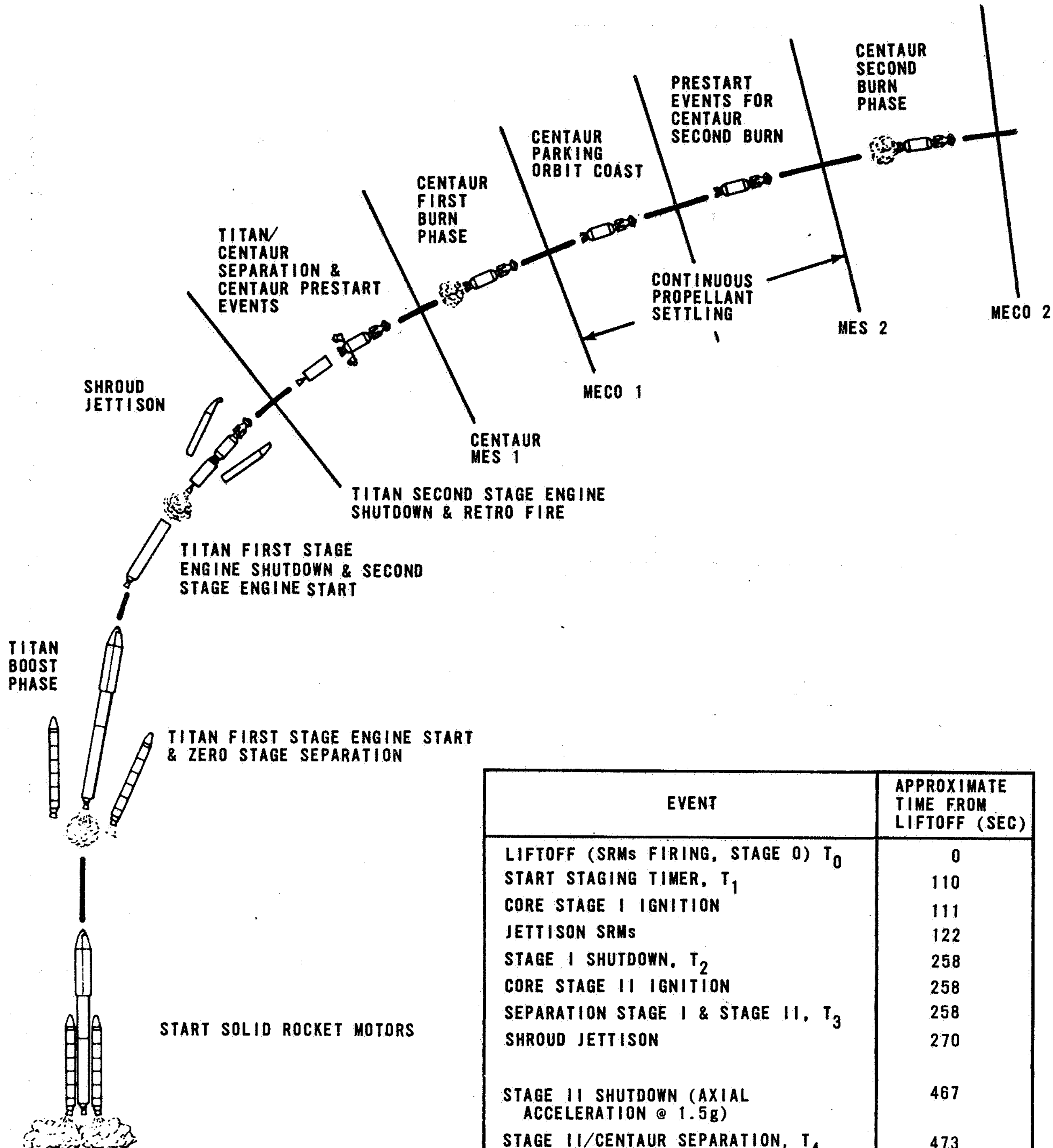


Figure 2.1 TITAN/CENTAUR Proof Flight (TC-1)



TC-1 TC-2 TC-4 & TC-3

Figure 2.2 Spacecraft Configurations for TC-1, TC-2, TC-4 & TC-3



EVENT	APPROXIMATE TIME FROM LIFTOFF (SEC)
LIFTOFF (SRMs FIRING, STAGE 0) T_0	0
START STAGING TIMER, T_1	110
CORE STAGE I IGNITION	111
JETTISON SRMs	122
STAGE I SHUTDOWN, T_2	258
CORE STAGE II IGNITION	258
SEPARATION STAGE I & STAGE II, T_3	258
SHROUD JETTISON	270
STAGE II SHUTDOWN (AXIAL ACCELERATION @ 1.5g)	467
STAGE II/CENTAUR SEPARATION, T_4	473
MES 1, CENTAUR FIRST BURN	483
MECO 1, CENTAUR MAIN ENGINE CUTOFF, FIRST BURN	617
MES 2, CENTAUR SECOND BURN	1341
MECO 2, CENTAUR MAIN ENGINE CUTOFF, SECOND BURN	1392

Figure 2.3 Typical Titan Centaur Launch Trajectory

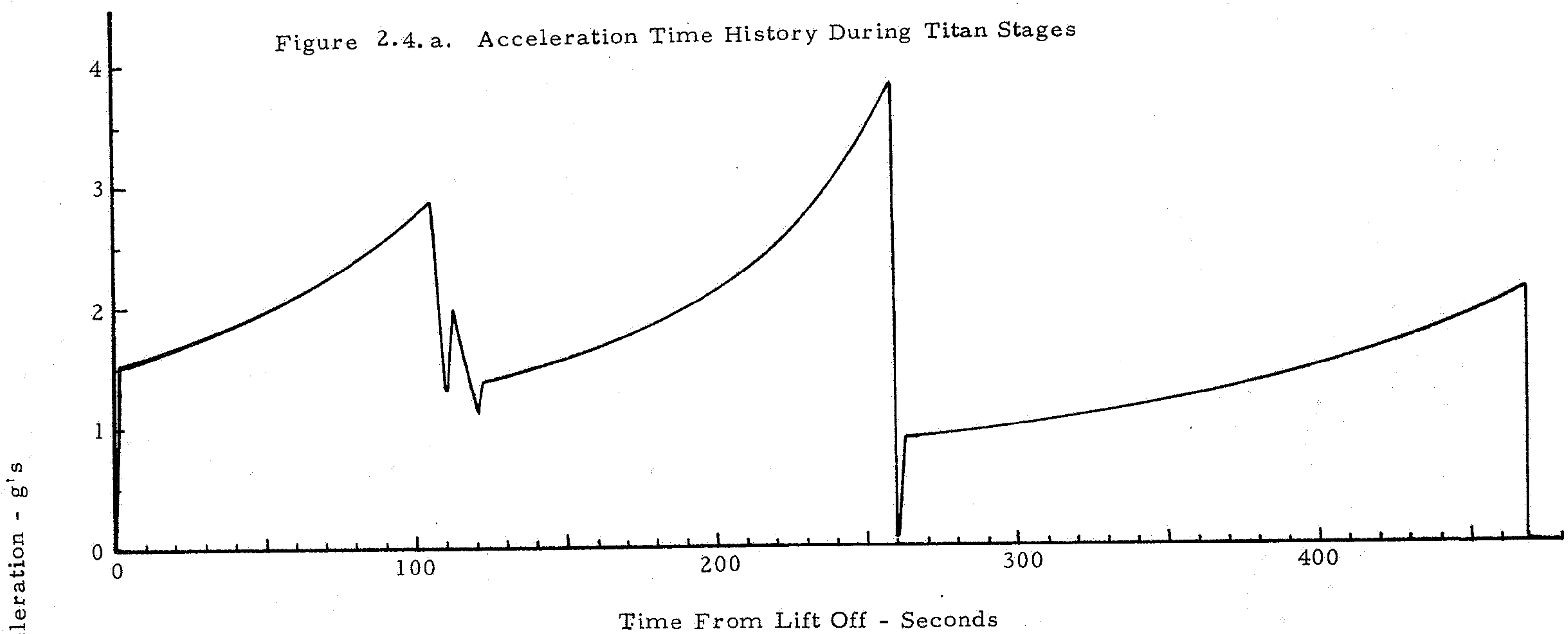


Figure 2.4.a. Acceleration Time History During Titan Stages

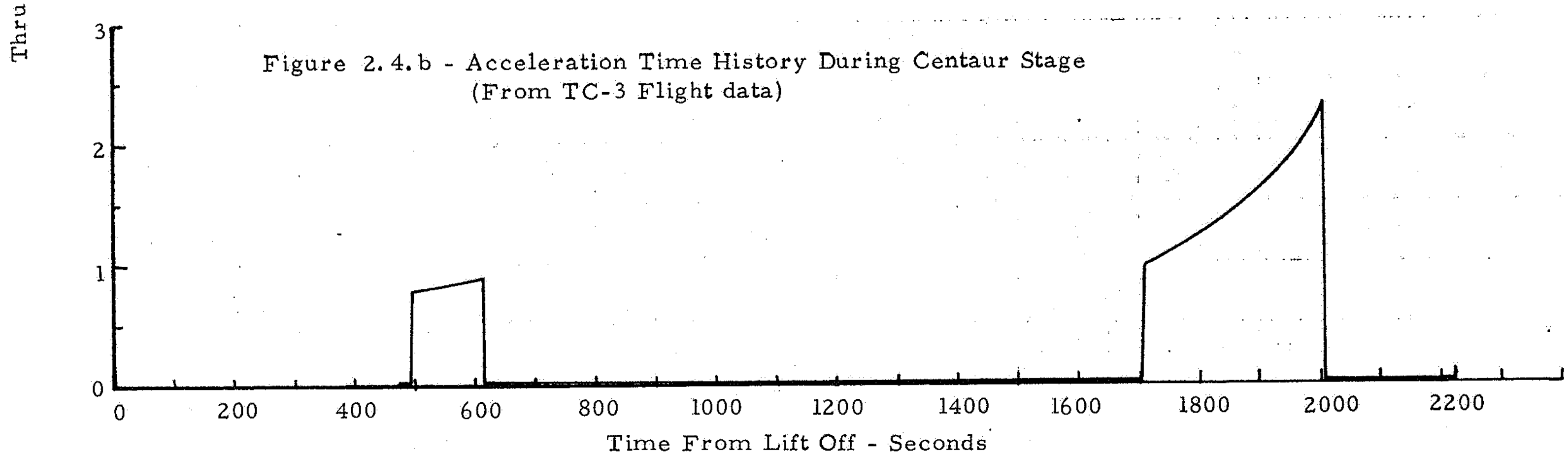


Figure 2.4.b - Acceleration Time History During Centaur Stage
(From TC-3 Flight data)

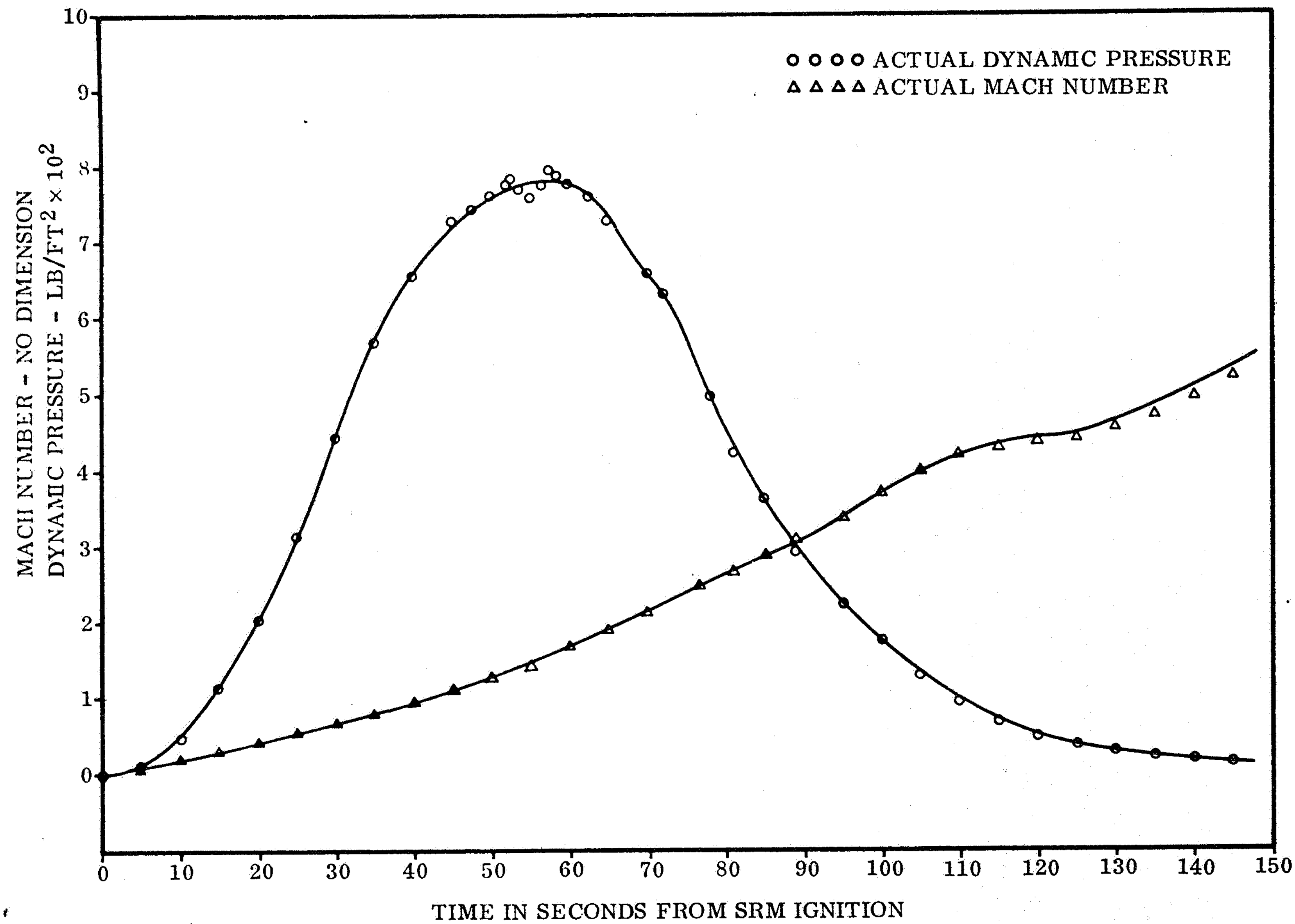


Figure 2.5 Titan Centaur Mach Number and Dynamic Pressure History

3. Flight Instrumentation Description

The instrumentation carried on the four flights for spacecraft environment evaluations consisted of microphones, vibration sensors, accelerometers, strain gages and pressure transducers. A summary of these measurements is presented in Table 3.1. Detailed information is contained in Tables 3.2 through 3.5 and Figure 3-1.

The microphones were at three station locations so that a measure of variation along the length of the Centaur and Spacecraft was obtained as well as variations between the four flights.

The vibration sensors were intended to provide a measure of the high frequency vibration environment. The accelerometers and strain gages were primarily for defining the lower frequency loading conditions on the spacecraft. The two pressure transducers on each of the Viking flights provided venting data for the shroud and the spacecraft.

Table 3.1 Summary of Payload Related Dynamic Instrumentation on TC-1 through 4

Launch Vehicle	Microphones (all inside shroud)	Vibration Sensors	Accelerometers	Strain Gages	Details
TC-1	2 - Spacecraft - Fwd Centaur	1 - Spacecraft	7 - Spacecraft	6 - Lander Adapter 2 - S/C Adapter	Tables 3.2 & 3.5
TC-2	3 - Spacecraft - Fwd Centaur - Aft. Centaur	3 - Spacecraft	3 - Payload	None	Table 3.3
TC-3	1 - Fwd Centaur	4 - Spacecraft	-	6 - Lander Adapter	Tables 3.4 & 3.5 & Fig. 3.1
TC-4	1 - Fwd Centaur	4 - Spacecraft	-	6 - Lander Adapter	"

Note: There were a varying number of vibration sensors and accelerometers located on the Centaur and Titan which were analyzed and reported by the launch vehicle agencies. There were also two pressure transducers on each of the Viking flights to measure shroud and spacecraft venting pressures: See Table 3.3.

Table 3.2 TC-1 MEASUREMENT LIST CENTAUR FM/FM #2 2215.5 MHz

VCO Number	Measurement Number	Description	Zero Load Bias	Full Scale Range	Filter Cutoff Frequency (Hz) A	B
3	CY216-S	V-S/C-A Axial Load Transducer	59%	25342 lbs	—	—
4	CY215-S	V-S/C-A Axial Load Transducer	59%	25331 lbs	—	—
5	CY208-Φ	VODS Sprung Mass Z-Axis Accelerometer	20%	10.01 g's	—	—
6	CY207-Φ	VODS Bus X-Axis Accelerometer	50%	10.00 g's	—	—
7	CY206-Φ	VODS Bus Y-Axis Accelerometer	50%	9.99 g's	—	—
8	CY205-Φ	VODS Bus Y-Axis Accelerometer	50%	10.01 g's	45	90
9	CY204-Φ	VODS Bus Z-Axis Accelerometer	50%	20.00 g's	200	118
10	CY203-Φ	VODS Bus Z-Axis Accelerometer	50%	19.98 g's	180	162
11	CY202-Φ	VODS Bus Z-Axis Accelerometer	50%	20.00 g's	160	—
12	CY214-S	PFLA Truss Axial Load, Member 202	59.6%	27177 lbs	153	—
13	CY213-S	PFLA Truss Axial Load, Member 203	61.0%	27192 lbs	145	—
14	CY212-S	PFLA Truss Axial Load, Member 204	61.1%	27157 lbs	140	—
15	CY211-S	PFLA Truss Axial Load, Member 205	59.2%	26636 lbs	137	—
16	CY210-S	PFLA Truss Axial Load, Member 206	60.1%	27175 lbs	135	—
17	CY209-S	PFLA Truss Axial Load, Member 201	61.6%	27319 lbs	134	—
18	CY201-Φ	Piezoelectric Accelerometer, Z-Axis	50%	40.0 g's	133	2100
19	CY217-Y	Acoustic Microphone	50%	150.0 dB	—	2800
		CENTAUR FM/FM #1 2208.5 MHz				
19	CA886Y	Acoustic Microphone Fwd Equip Comp	50%	150.0 db	—	—

A. Filter set used with 1024 sps digitization rate. Design for minimum phase error (below 40 Hz) between channels 9 through 18.

B. Filter set used with 8192 sps digitization = double standard IRIG

Table 3.3 DYNAMIC MEASUREMENTS - TC-2 FLIGHT - HELIOS SPACECRAFT

MEASUREMENT			Range				FM/FM	
No.	Description	V-S/C Axis	Low	High	Units	SPS	VCO No.	Freq. (1) Cont.
CA 685Ø	P/L Adapter Longit.		-2	8	G	1115	------	----------
CM 101A	Axial Accel. Fwd. Instrument Box		-2	8	G	557	------	----------
CA 888Y	Eng. Comp. Acoustics		120	150	Db	-	**20	1860
GA1A	AT Accel. (Thrust)	Z	-5	+20	G		14	330
GA2A	AY Accel. (Yaw)	Y	+4	-6	G		13	218
GA3A	AP Accel. (Pitch)	X	+4	-6	G		12	158
GA4A	Accel. Low Level	Z	-.5	+.5	G		10	81
GA1Ø	X T Vib. (Thrust)	Z	-25	+25	G		17	780
GA2Ø	X P Vib. (Pitch)	X	-25	+25	G		16	600
GA3Ø	X Y Vib. (Yaw)	Y	-25	+25	G		15	450
GA1Y	Acoustic		120	150	db		19	1395

(1) Frequency content is for Mod Index of 5. Higher frequency can be extracted if signal to noise ratio is good.

(2) Measurements on Helios Support Fitting

Table 3.4 TC-4 and TC-3. FM/FM TELEMETRY INSTRUMENTATION, 2208.5 MHz LINK

MEAS. NO.	DESCRIPTION	JPL DESIGNATION	RANGE		UNITS	ACCURACY	FM/FM CHANNEL	FILTER CUT OFF FREQUENCY - Hz	
			LOW	HIGH				A 1024 SPS	B 4096 SPS
CA886Y	Fwd.Equip.Comp.Amb.	-	120	150	db	5%	19	—	2800
CY182Ø	Longit.Vib; Foot H	2001AC1	-30	30	G	5%	18	133	2100
CY183Ø	Radial Vib.; Bay 7/8	2001AC2	-12	+12	G	5%	17	134	1580
CY184Ø	Longit. Vib., Foot C	2001AC3	- 5	+ 5	G	5%	16	135	1200
CY185Ø	Longit. Vib., Foot R	2001AC4	- 5	+ 5	G	5%	15	137	900
CY186S	VLCA #750 Strain 1	2001SG1	10000C	8000T	Lbs	5%	14	140	—
CY187S	VLCA #751 Strain 2	2001SG2	10000C	8000T	Lbs	5%	13	145	—
CY188S	VLCA #752 Strain 3	2001SG3	10000C	8000T (1)	Lbs	5%	12	153	—
CY189S	VLCA #753 Strain 4	2001SG4	10000C	8000T	Lbs	5%	11	160	—
CY190S	VLCA #754 Strain 5	2001SG5	10000C	8000T	Lbs.	5%	10	180	—
CY191S	VLCA #755 Strain 6	2001SG6	10000C	8000T	Lbs.	5%	9	200	—
CY192P	VLC Bioshield DP		-0.25	0.75	PSID	5%	4	—	—
CY193P	VLC Bioshield Press.		0	16	PSIA	5%	3	—	—

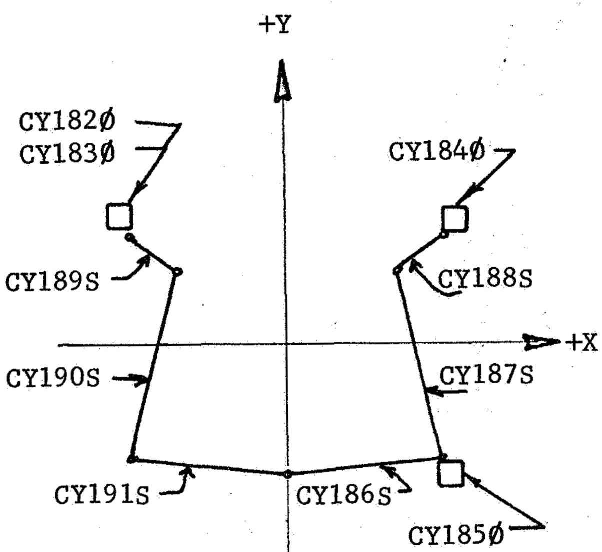
(1) Range shown is max limit. Each gage will have a different range dependent on its calibration value.

A. This is a special set of filters which, in conjunction with discriminator characteristics, results in phase errors of less than 1° between VCO 9 through 18 below 40 Hz

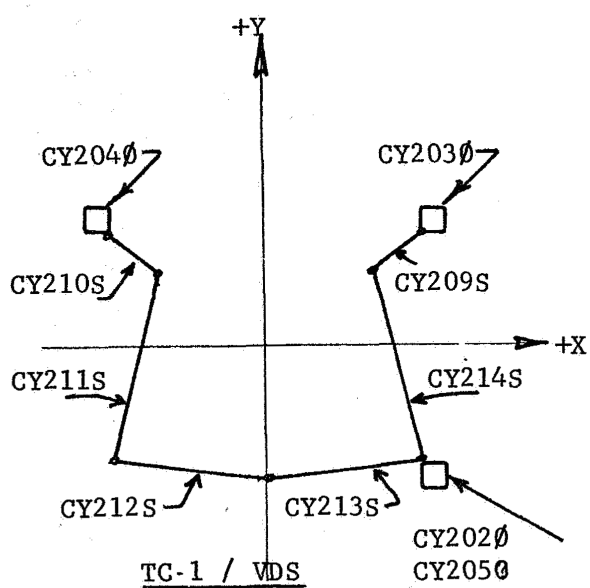
B. These are twice the standard IRIG filter.

Table 3.5 MEASUREMENTS CORRESPONDENCE VIKING SPACECRAFT TO VDS

VIKING (TC-4 & 3) IRIG NO.	VIKING (TC-4 & 3) SENSOR		VDS (TC-1) SENSOR	VDS (TC-1) IRIG NO.
9	CY191S	↔	CY212S	14
10	CY190S	↔	CY211S	15
11	CY189S	↔	CY210S	16
12	CY188S	↔	CY209S	17
13	CY187S	↔	CY214S	12
14	CY186S	↔	CY213S	13
15	CY185Ø	↔	CY201Ø	18
16	CY184Ø	↔	CY203Ø	10
17	CY183Ø	↔	CY205Ø	8
18	CY182Ø	↔	CY204Ø	9



VIKING / TC-3&4



TC-1 / VDS

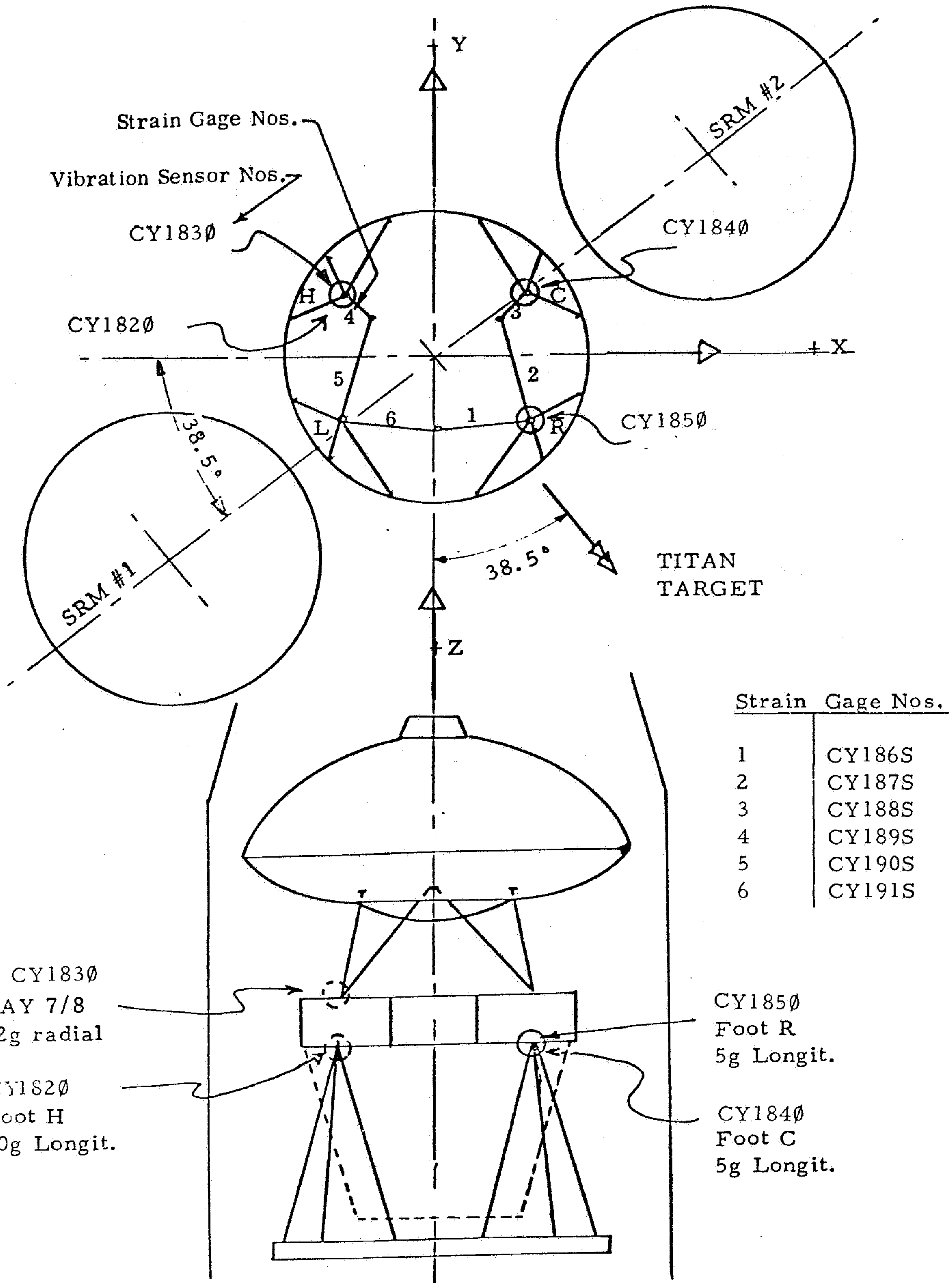


Figure 3.1 VIKING SPACECRAFT INSTRUMENT LOCATIONS

4. Data Acquisition and Analysis Plan

The total measurement, acquisition and analysis effort was the cooperative effort of many government agencies and their contractors. The data of this report, with a few exceptions which are noted, are the results of processing and analysis performed at the NASA Langley Research Center under the direction of the Viking Project Office.

5.1 Acoustic Data

This section presents 1/3 octave band spectra of acoustic measurements made on the four Titan Centaur Launch Vehicles, TC-1 through TC-4. There were two microphones on TC-1, three on TC-2 and one each on TC-4 and TC-3. The measurement in the Centaur Forward Equipment Compartment (CA886Y) was common to all four flights. The general data procedure followed was to perform analyses of successive two second periods of time at lift off and through Max Q. This then shows variations of frequency spectra as well as overall levels. A listing and description of the instrumentation can be found in the Appendix.

A summary of wide band acoustic levels is given in Table 5.1.1 for the two frequency bands of 10-2000 Hertz and 0-2000 Hertz. The difference in levels between these two frequency bands indicate the amount of low frequency acoustics present. Significant differences are seen in the first two seconds following Stage 0 Ignition because of the relatively large, low frequency "overpressure" phenomenum. There are also some very low frequency variations in the Mach 1 - Max Q period of flight probably caused by the movements of unstable shock waves.

The Octave Band data shown in Figure 5.1.1 were developed by the NASA Kennedy Space Center. All other data presented here was processed by NASA Langley Research Center.

Figure 5.1.1 presents plots showing the variation of overall and several Octave Band acoustic levels as a function of flight time. The complete set of Octave band data is contained in Volume I of Reference 3, however the 2, 250 and 2000 Hertz octave band data shown here comprises the most significant data. The 2 Hz band shows there are large amplitude low frequency pressure fluctuations both at Stage 0 Ignition and in the Transonic-Max Q region of flight. The 250 Hz OB has the most significant levels both at lift-off and at Mach 1. The 2000 Hz OB shows that the frequency spectrum shifts upward after Max Q and is maintained at the 116-118 Db level for about 30 seconds. The total duration of the acoustic environment is roughly 8 seconds at lift off and 30 seconds at Max Q/Mach 1.

A summary of 1/3 octave band spectra from all four flights is presented in Figure 5.1.2 for Lift Off and Max Q. This figure also makes comparisons to Flight Acceptance (FA) test spectra used for the Viking Lander Capsule (VLC) and Viking Orbiter (VO). Both the VLC and VO spec requirements are seen to be lower than lift off acoustics in the frequency range below 50 Hz. This is a result of the unexpected overpressure phenomenum at Stage 0 Ignition. The VLC test requirement is seen to also be low in the frequency range above 1000 Hertz. These spec deficiencies were not considered serious for the reasons that the acoutic environment in the mid frequencies (100 - 500 Hz) are generally the most damaging and the specification spectrum levels were 4 to 8 Db higher than the flight envelope in that frequency band.

It should be noted that the separate spectra that go to make up the envelope spectra are not so flat as the envelope spectra. This is due to the fact that the acoustic environment on the spacecraft is continually shifting in spectrum. At Stage 0 Ignition the spectrum has its highest levels in the low frequencies. As the launch vehicle lifts off, the overpressure effects die out and the SRM thrust chambers come out of the deflector bucket with the net result that the spectrum shifts to peak out between 200 and 600 Hertz. Similarly in the Mach 1 region the spectrum peaks out close to 250 Hertz and then shifts upward to a relatively flat spectrum with maximum in the 1000-2000 Hertz range.

Figure 1. 3 through 1. 8 present additional envelope spectra showing the variation from flight to flight and between measurement location. A compilation of the separate spectra which were used in establishing these envelopes is presented in Volume 1 of Reference 3.

TABLE 5.1.1 TITAN CENTAUR ACOUSTIC DATA
SUMMARY OF WIDEBAND LEVELS

FLIGHT & SENSOR	LIFT OFF			MAX Q		
	T+0 to T+2	T+2 to T+4	T+4 to T+6	Pre Max	Max.	Post Max
TC-1						
-CY217Y	126.4 (134.5)	123.5 (125.6)	123.6 (124.3)	119.2 (119.8)	116.8 (125.0)	116.6 (119.9)
-CA886Y	128.6				124.8	
TC-2						
-GA1Y	127.3 (135.8)	126.0 (128.5)	126.4 (126.7)	121.7 (121.9)	123.6 (123.7)	122.0 (128.0)
-CA886Y	129.5 (135.3)	126.7 (128.4)	126.6 (126.9)	123.6 (123.7)	126.5 (126.6)	122.9 (125.0)
-CA888Y	128.1 (142.4)	127.4 (130.9)	125.4 (127.2)	121.8 (122.4)	123.4 (125.2)	122.4 (125.8)
TC-4						
-CA886Y	130.3 (138.1)	124.6 (126.3)	125.6 (125.7)	124.3 (124.5)	124.8 (124.8)	121.9 (122.5)
TC-3						
-CA886Y	129.2 (138.9)	125.0 (125.7)	(Not Done)	124.3 (124.4)	124.8 (125.0)	120.8 (122.2)

Locations:
CA886Y - Centaur Fwd Equipment Compartment
CA888Y - Centaur Engine Compartment
CY217Y - TC-1 Payload (VO Bus)
GA1Y - TC-2 Payload (Helios Attach Frame)

Units - Db re .0002 dyne/cm^2 10 - 2000 Hz BW
(Numbers in parentheses are for the 0-2000 Hz frequency band)

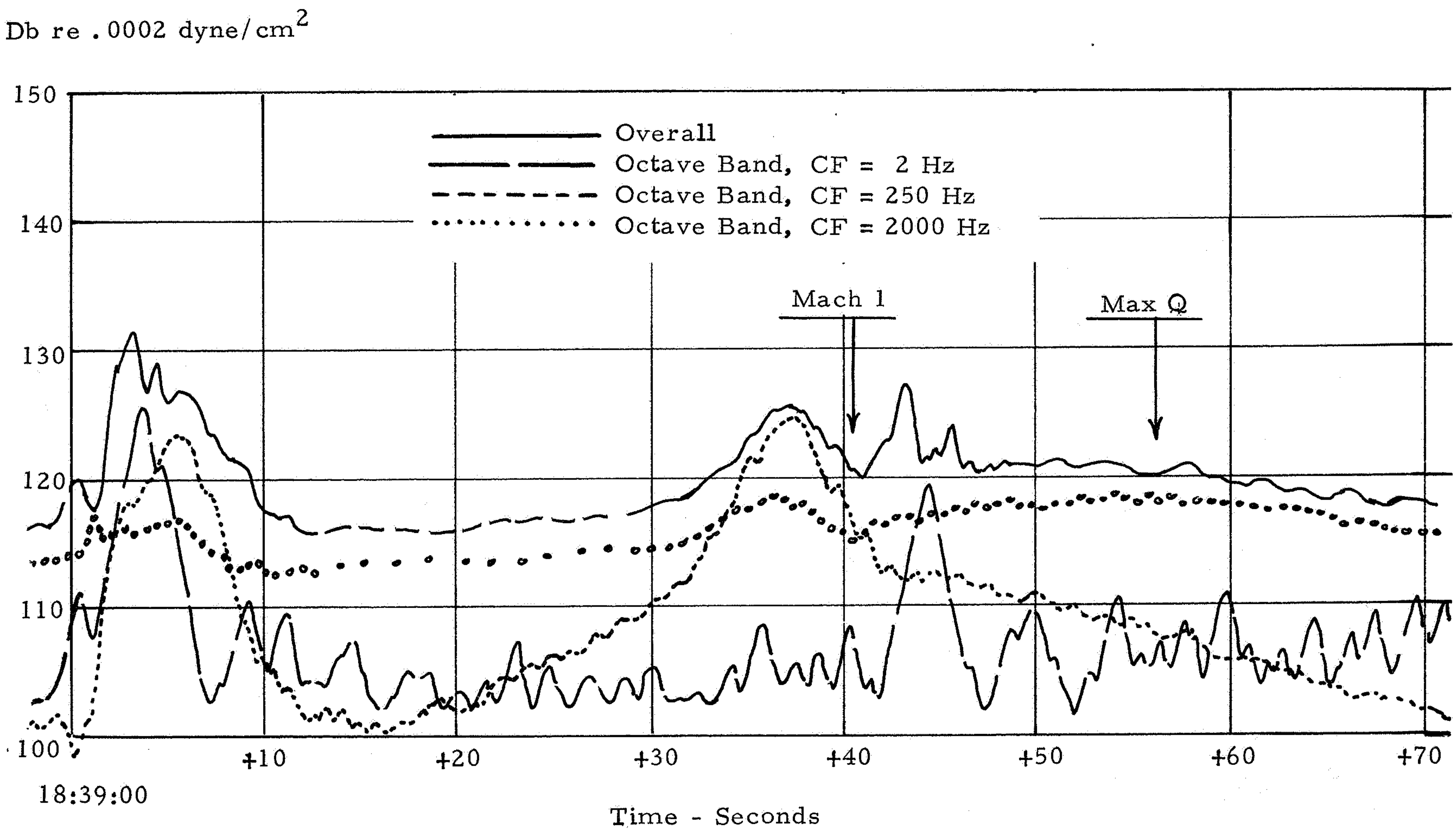


Figure 5.1.1 - Variation with Flight Time of Overall and Selected Octave Band Acoustic Levels, TC-3 Data (data by KSC)

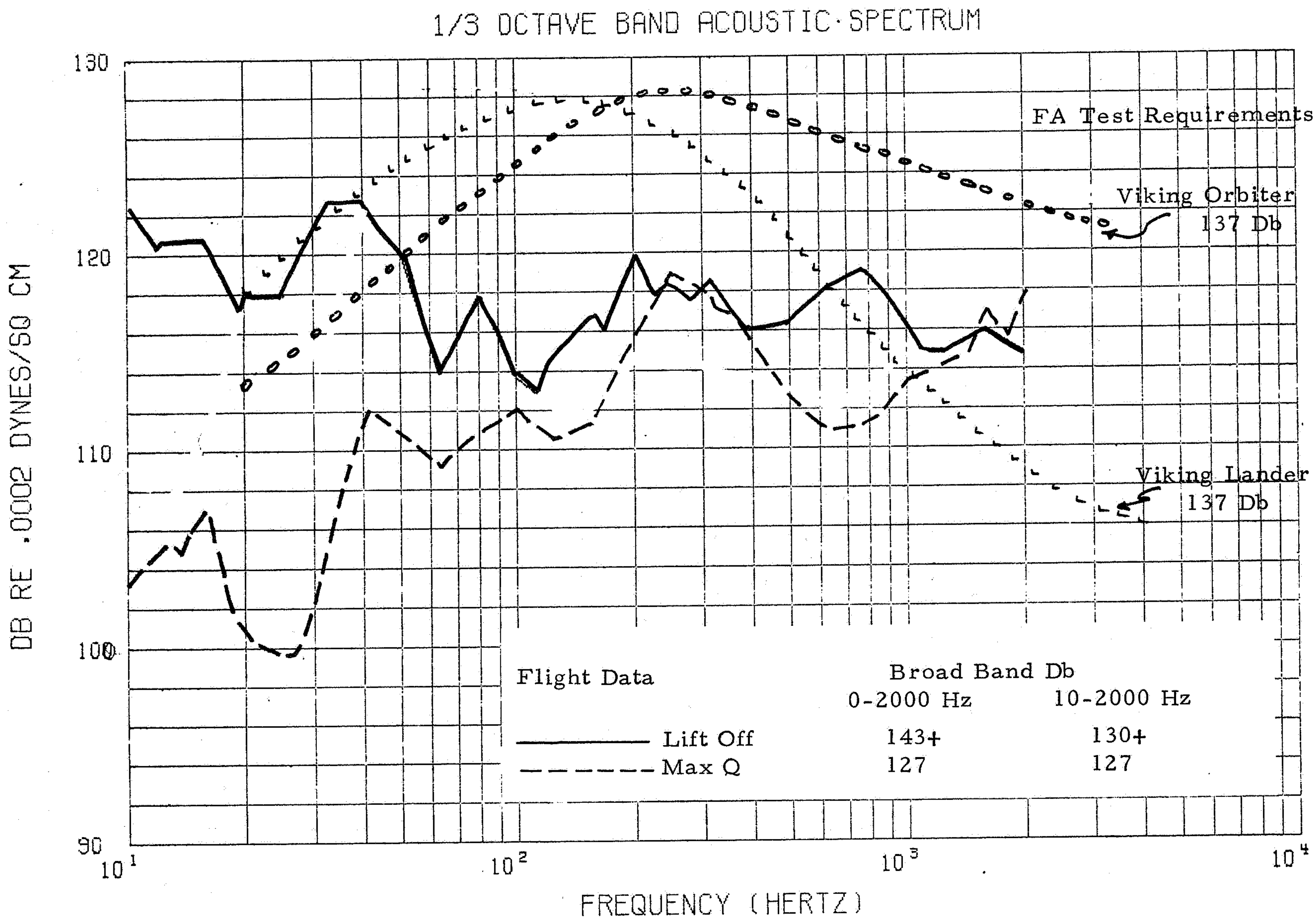


Figure 5.1.2 Envelope of All Measurements & All Flights Compared to Viking Test Specifications

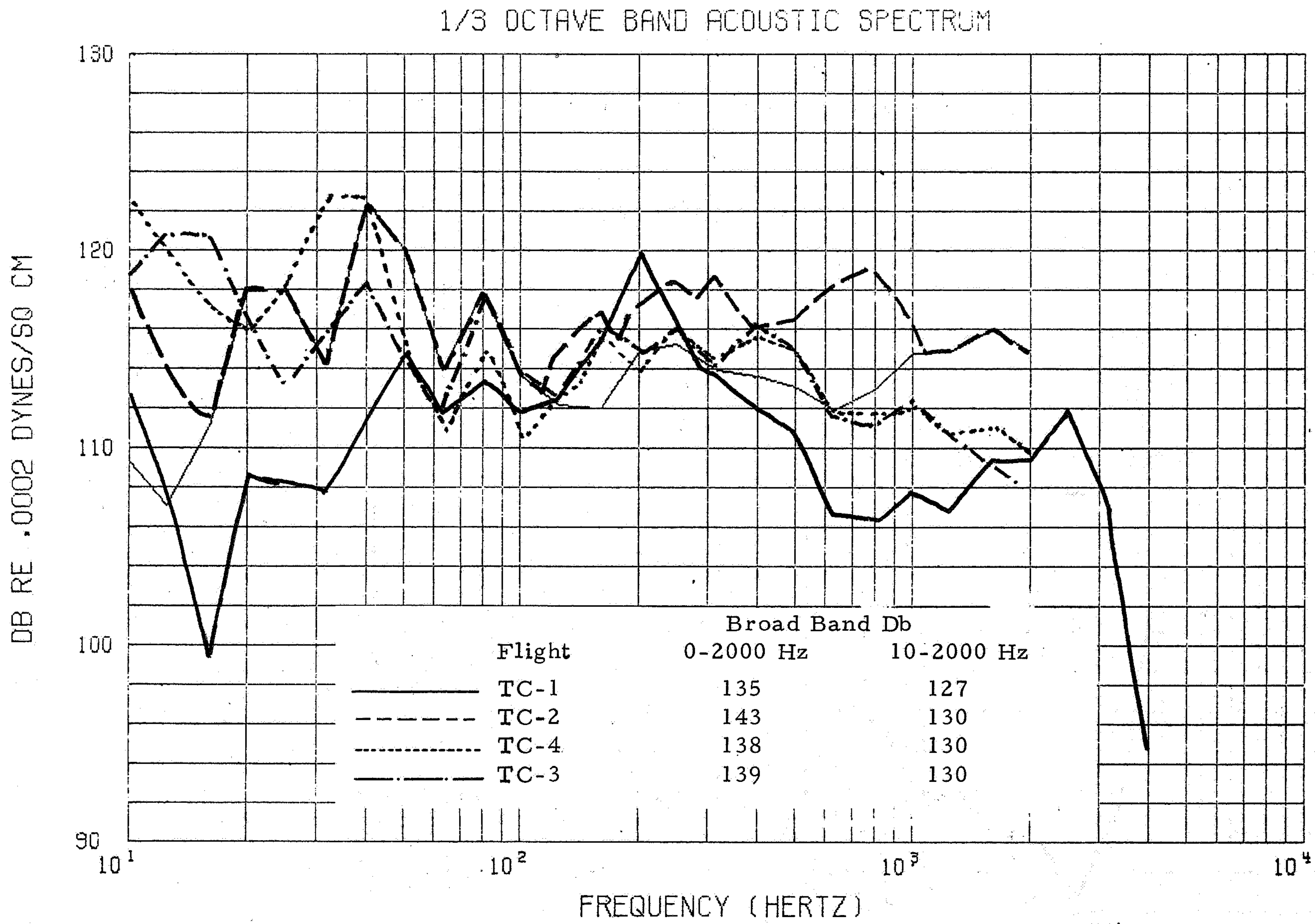


Figure 5.1.3 Comparison by Flight of Lift Off Spectra

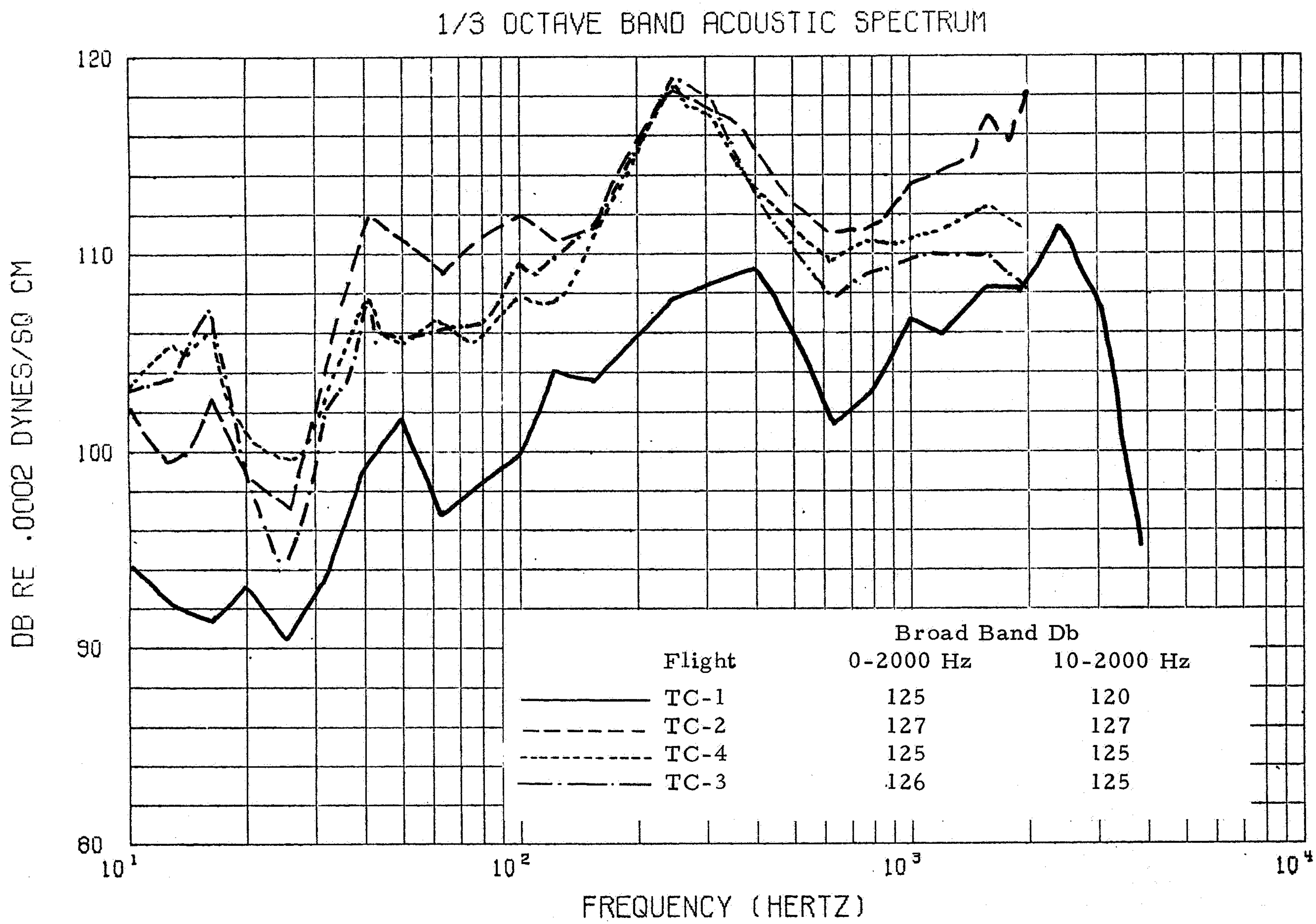


Figure 5.1.4 Comparison by Flight of Max Q Spectra

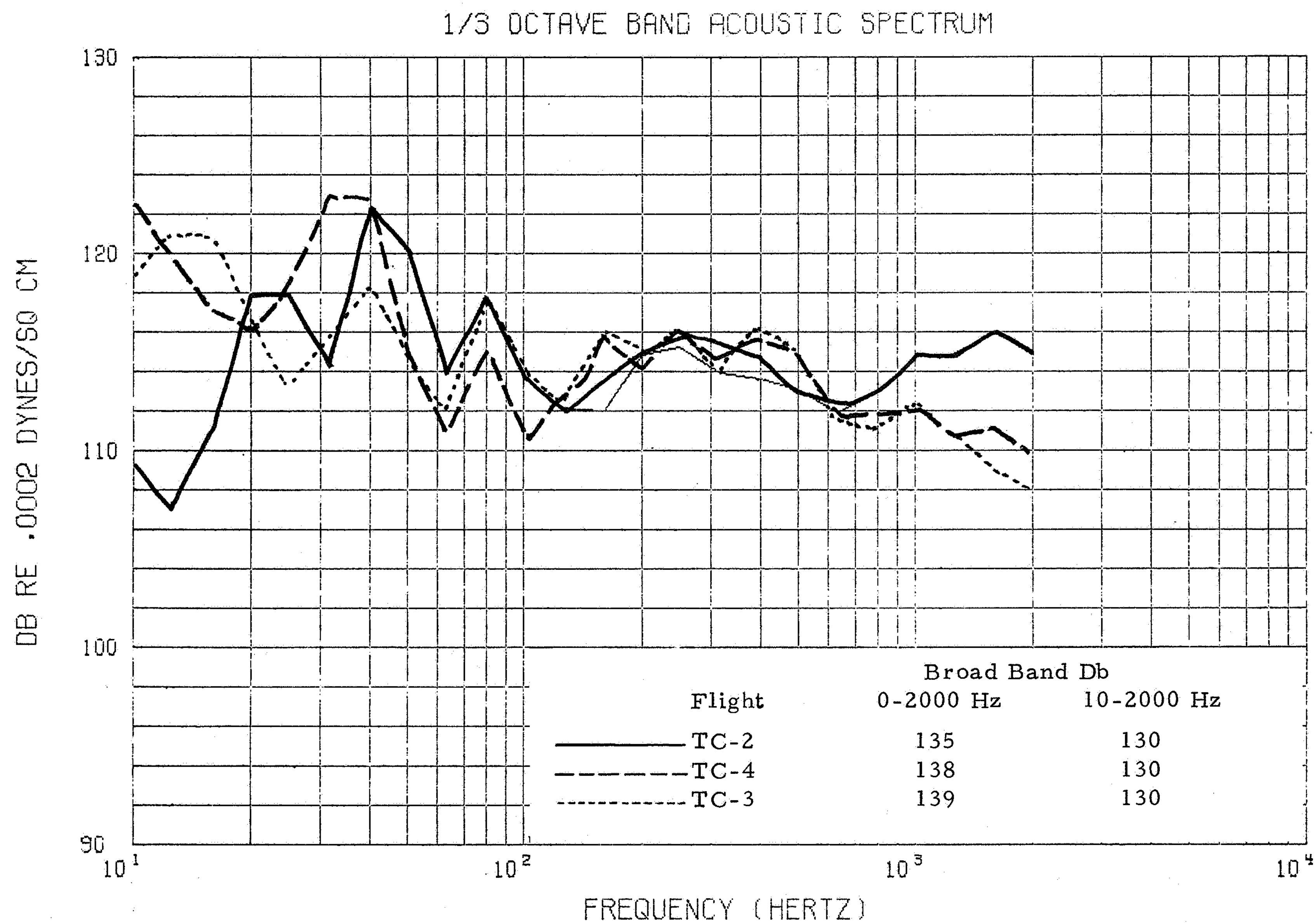


Figure 5.1.5 Comparison by Flight, for Lift Off, CA 886Y

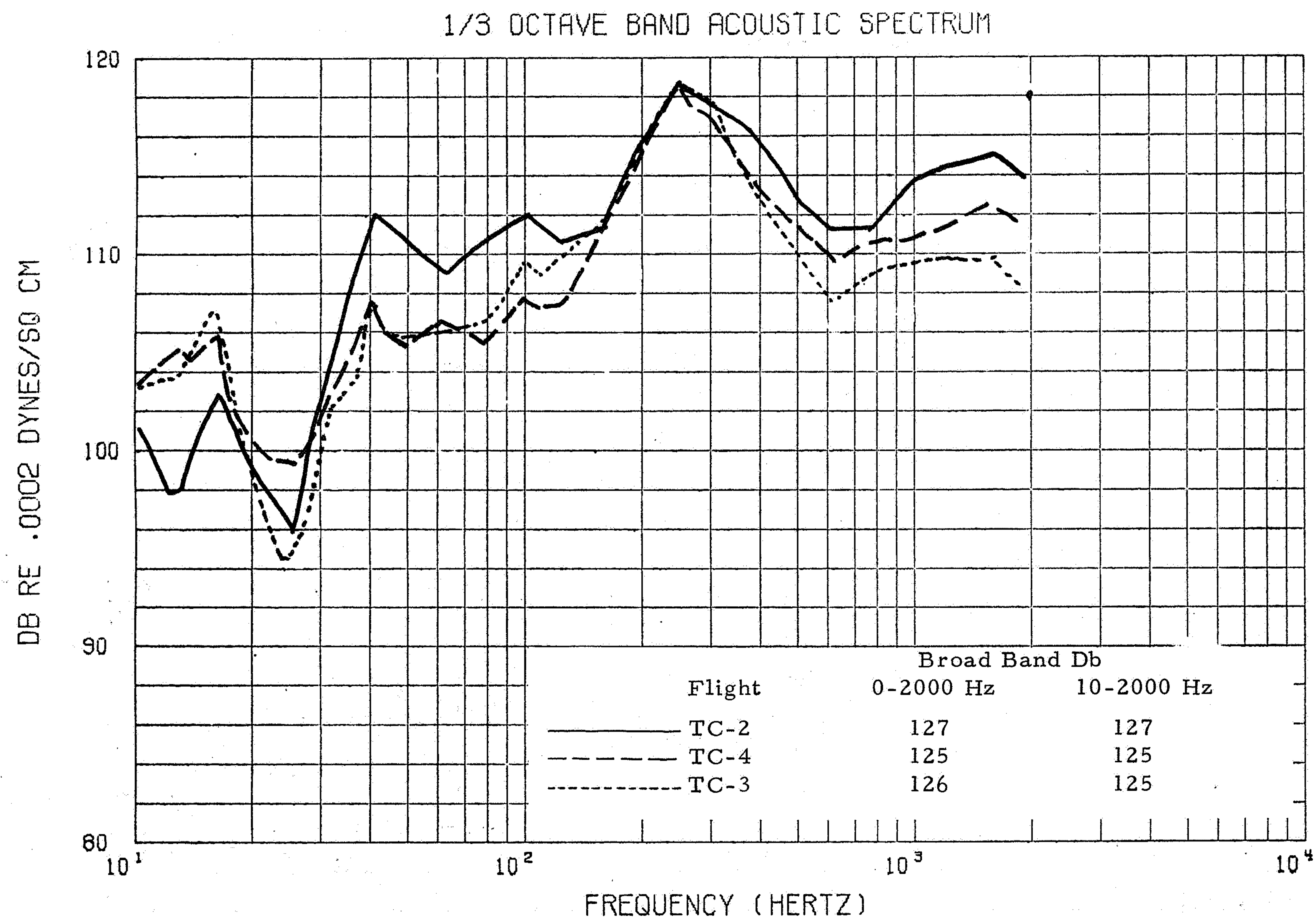


Figure 5.1.6 Comparison by Flight, for Max Q, of CA 886Y

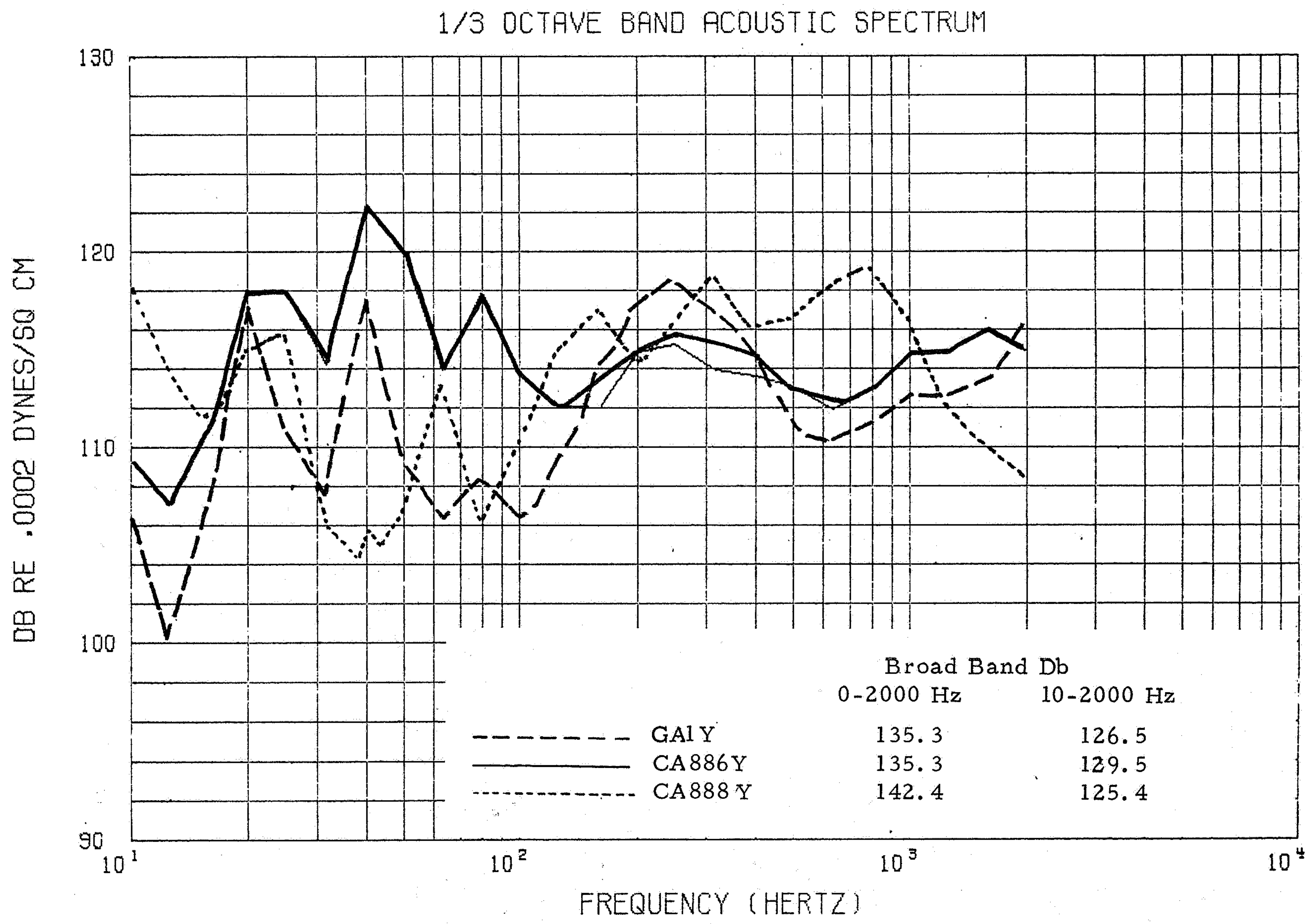


Figure 5.1.7 Comparison by Location of TC-2 Lift Off Data

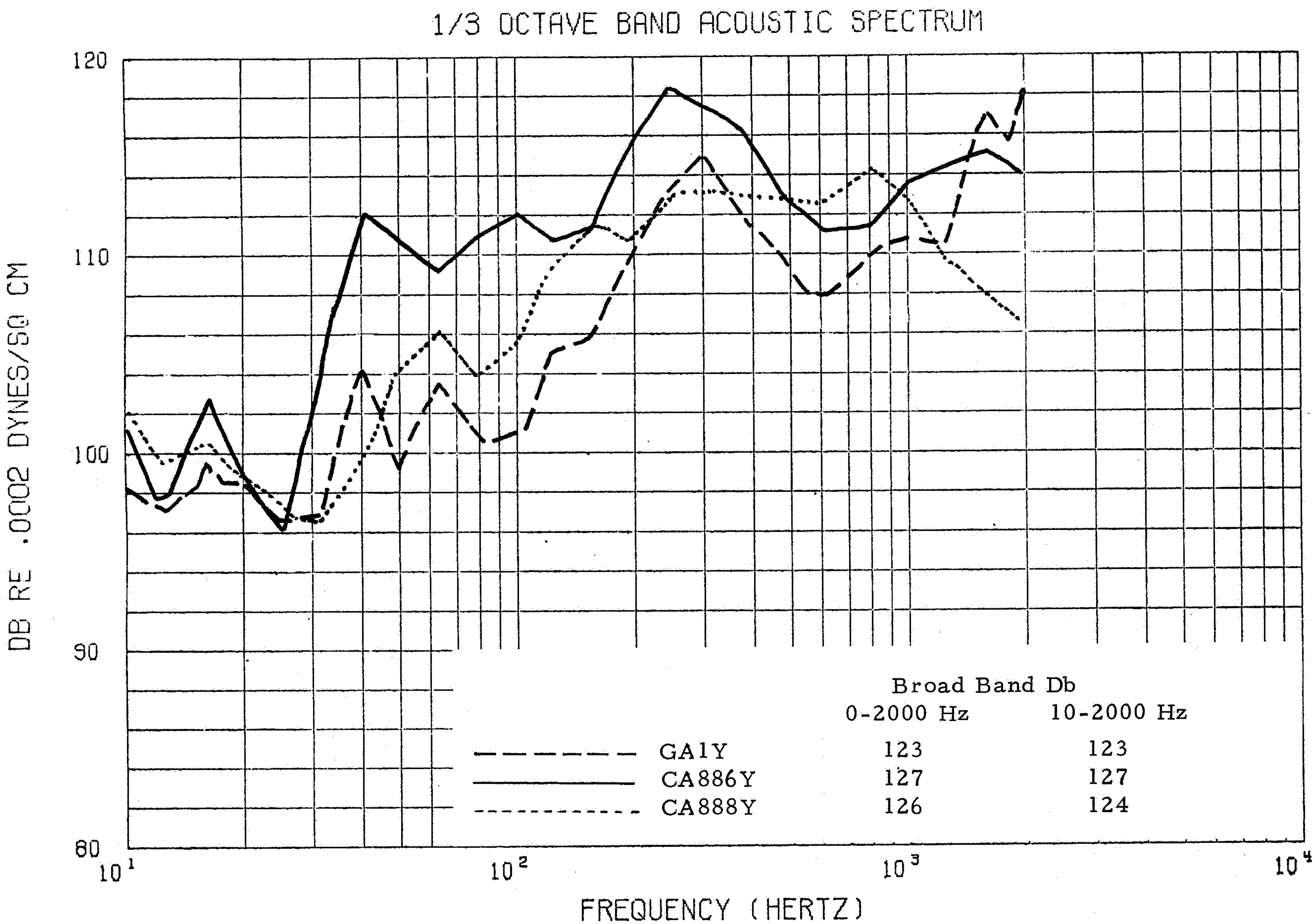


Figure 5.1.8 Comparison by Location of TC-2 Max Q Data

5.2 Vibration Data - Viking Requirements Comparison

There were several vibration sensors and accelerometers flown on the space flight launchings which are the subject of this report. A listing of sensors and locations can be found in Section 3. The accelerometers were of the servo type and were intended to be used primarily for low frequency phenomena, low frequency being in the 0-100 Hertz range. The vibration sensors were crystal type sensors and were intended to cover the higher frequency ranges, up to the limits of the particular telemetry channel.

The vibratory environments on the Viking Spacecraft were divided into three types: (1) sinusoidal vibrations primarily in the 5 to 200 Hertz range which were based on an equivalence to booster event, transient vibrations; (2) random vibrations as caused by acoustic loadings; and (3) shock as caused by pyrotechnically actuated events and high frequency booster events. The acoustically induced random vibration is the subject of this section.

A summary of all the vibration and acceleration data obtained on TC-1, TC-4 and TC-3 is shown on Figures 5.2.1 and 5.2.2. The Viking Lander Capsule (VLC) cg data shown in Figure 5.2.1 was obtained from transformation of the Lander Adapter (VLCA) strain data assuming the lander to be rigid. This data is frequency limited by special low pass filters, ranging from 140 to 200 Hertz that were designed to minimize phase errors between channels 9 through 18. Phase error was less than ± 1 degree below 40 Hertz and less than ± 10 degrees below 100 Hertz. The net result is that the VLC cg data shown in Figure 5.2.1 has its primary validity below 90 Hertz and is cut off by filtering starting at 140 Hertz.

The primary usefulness of the VLC cg PSD data is that it provides a measure of the low frequency structural loadings. The major response is at 5 Hertz. All significant responses are below 20 Hertz. The maximum PSD was .037 g^2/Hertz at 5 Hertz. The 1σ and 3σ values, from the individual PSD analyses, were all below .3g and .9g respectively.

The Viking Orbiter (VO) Bus data summarized in Figure 5.3.2 are PSD of vibration measurements digitized at 4096 sps (TC-4 and TC-3) or 8192 sps (TC-1). This data was played back through low pass filters of cut off frequencies twice the IRIG Standard. IRIG number 18 was the highest frequency channel used so that valid data to 2000 Hz was obtained.

A comparison was made of the high frequency vibration data measured in flight to the vibration response measurement made during the acoustic testing of the Viking Spacecraft. Figure 5.2.3 makes comparison of flight data to Viking Orbiter acoustic test data. A direct comparison was possible since vibration sensors were located in the same general position on the Orbiter Bus for both flight and ground test.

Two comparisons are made in Figure 5.2.3. First the vibration measurements in the 143.6 Db acoustic Proof Test are compared to the flight measurements. The Proof Test vibration are seen to be higher than flight measurements in the 40 to 1000 Hertz range generally by an order of magnitude. The second comparison made was to factor down the ground test vibration for an equivalence to the flight measured acoustic spectrum. For example at 300 Hz the proof test acoustic spectrum is 16 db higher than the flight measured spectrum, or a power ratio of .025. Thus the .007 g^2/Hz test response is reduced to .00018 g^2/Hz for a comparison to the flight data on the equivalent acoustic spectrum. For this comparison the TC-1 data was separated from TC-4 and TC-3 since the detail construction of the TC-1's Viking Dynamic Simulator was very different from the actual Viking Spacecraft.

Two observations are apparent. First the random vibration in acoustic Proof Test had more than adequate margin over flight measured random vibrations at the same measurement point. Second, on an equivalent acoustic spectrum level basis the flight vibration measurements were higher than ground test. Two explanations for the second observation come to mind. The first is that the response levels do not vary linearly with acoustic excitation levels. This is generally found to be true in the dynamic characteristics of aerospace structures. Second the secondary characteristics of the acoustic environment are not the same, comparing flight with acoustic chamber acoustics. For example it is possible that there are spatial correlation and directivity characteristics of the flight acoustics which can more effectively drive certain structural modes. Since there is no practical way to quantify these effects for any given spacecraft it is recommended that an additional margin be included between a predicted acoustic environment and its design requirement counterpart. On the basis of the data presented here this margin would seem to be between 6 and 9 Db.

The final comparison is shown in Figure 5.2.4 of Viking Lander Capsule test responses compared to flight measured VO Bus responses. Since the measurement locations are not the same, between flight and ground test, only general observation can be made. The equipment plate vibrations are well below the bus flight measurements based on equivalent acoustic spectrum excitation. This is as expected the equipment plate being heavily loaded and more removed from the acoustic source. Conversely the ground test vibration at the Aeroshell apex is considerably higher than flight measured bus vibration as expected due to the large surface area and light loading of the aeroshell.

The random vibration levels are seen to be low compared to the usual aerospace equipment test requirements. This was as predicted. There were some regions of the Viking Spacecraft where high levels of vibration were predicted and measured in ground test. The test requirements for components in these regions were defined according to those predictions. However a large portion of the components were tested to what was felt to be a minimal random vibration test necessary to demonstrate adequate quality of construction and workmanship. These minimum requirements are shown in Figure 5.2.5. However there were further reductions made on these "minimum" requirements in special cases as is sometimes the case where a compromise position is reached between risk, cost and schedule.

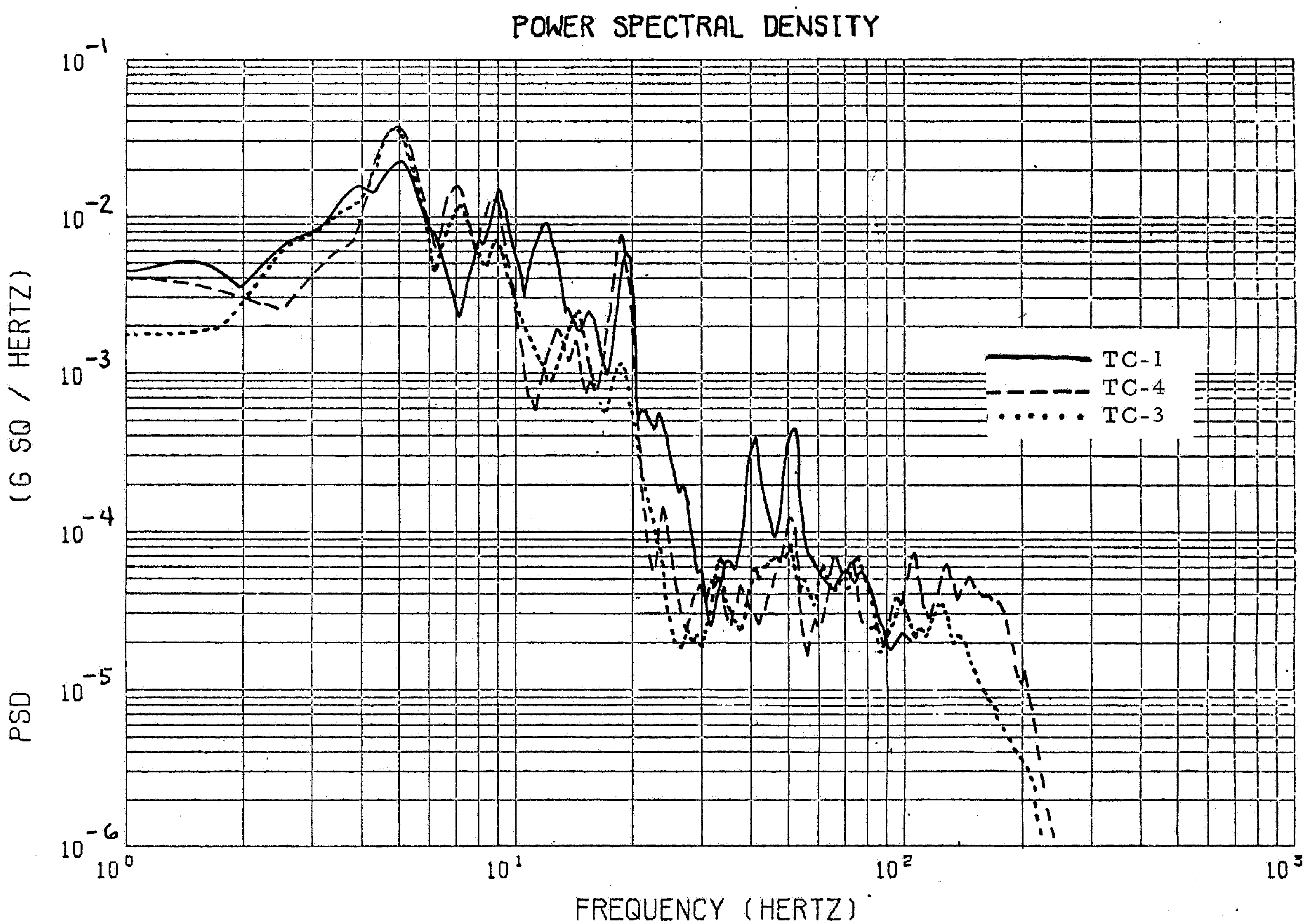


Figure 5.2.1 Envelope of Flight Vibration PSD, VLC cg., Developed from Strain Data Includes Lift Off and Max Q Data

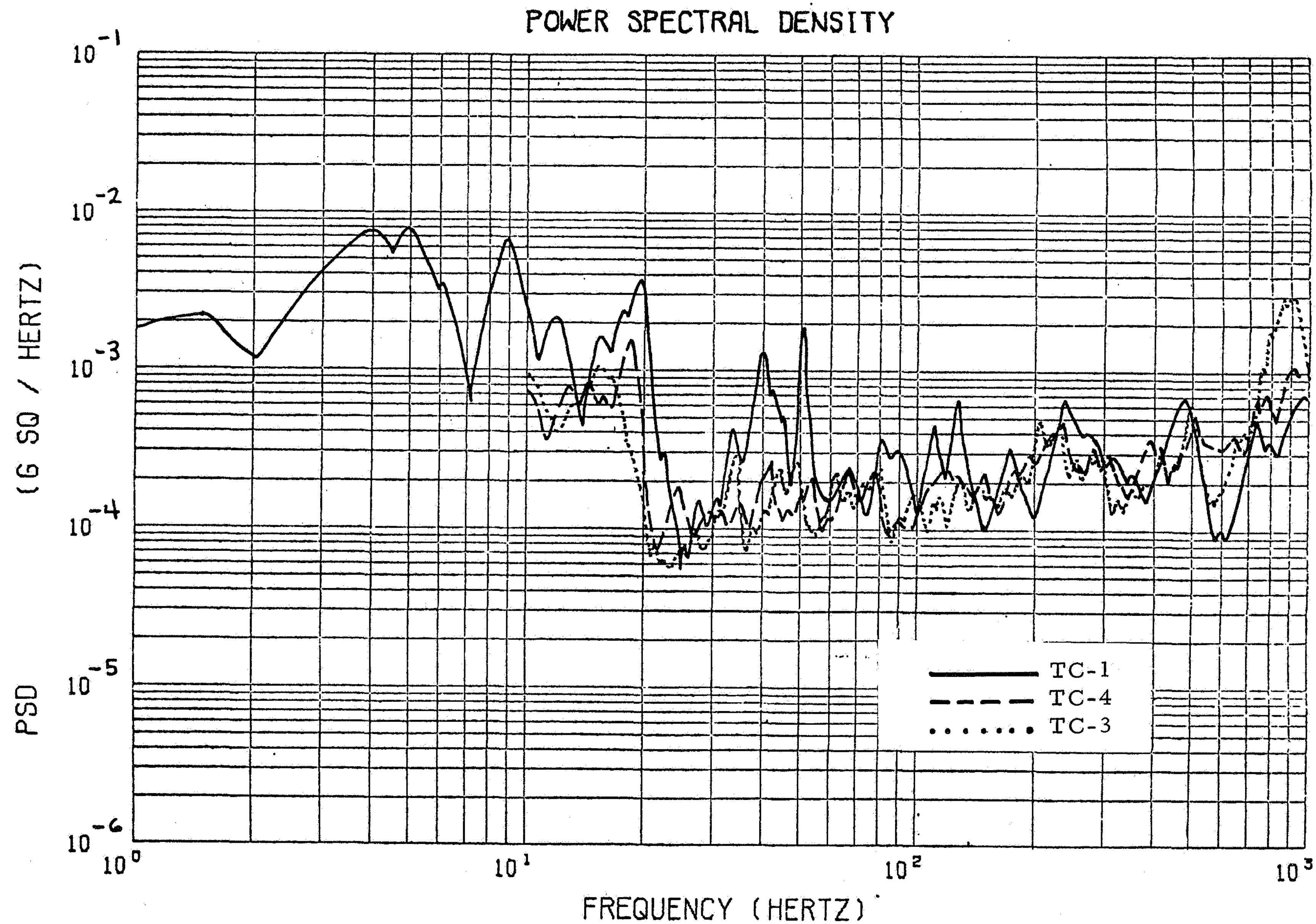


Figure 5.2.2 Envelope of Flight Vibration PSD of Measurements on VO Bus - Includes Lift Off and Max Q Data

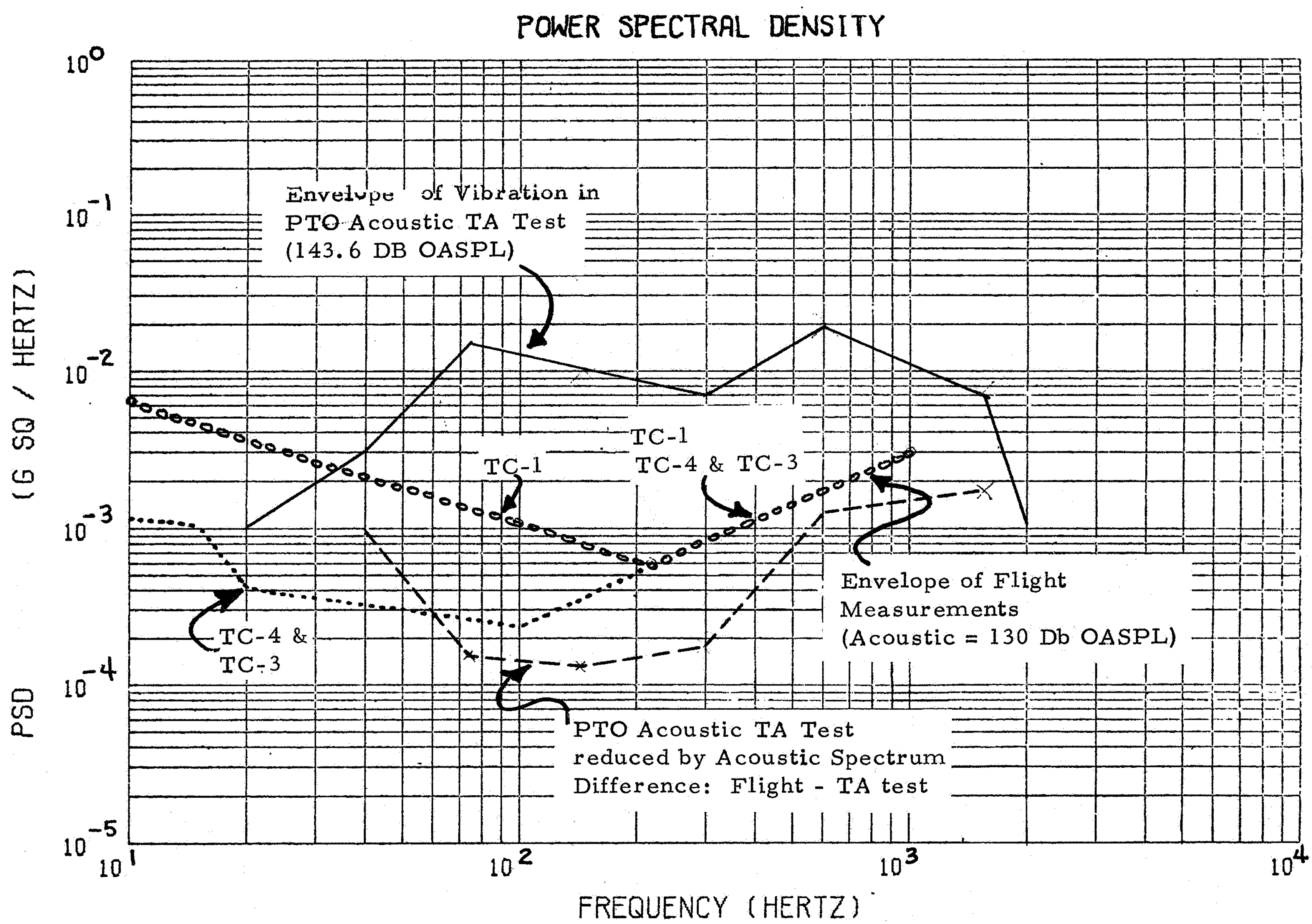


Figure 5.2.3. Comparison of Vibration Response Data of Viking Spacecraft from Flight and Laboratory Acoustic Test: JPL Orbiter Testing

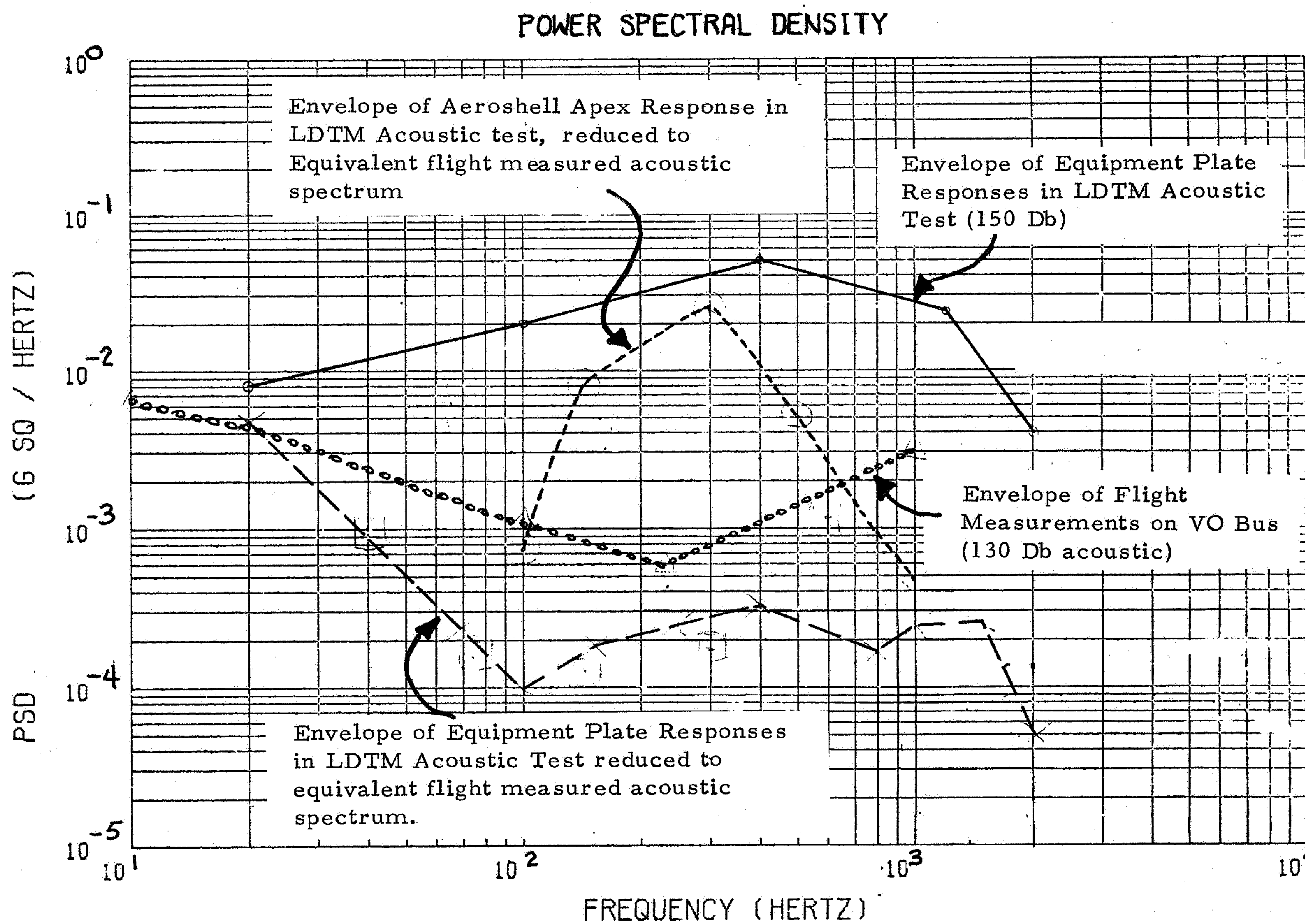


Figure 5.2.4. Comparison of Vibration Response Data of Viking Spacecraft from Flight and Laboratory Acoustic Test: MMC LDTM Testing

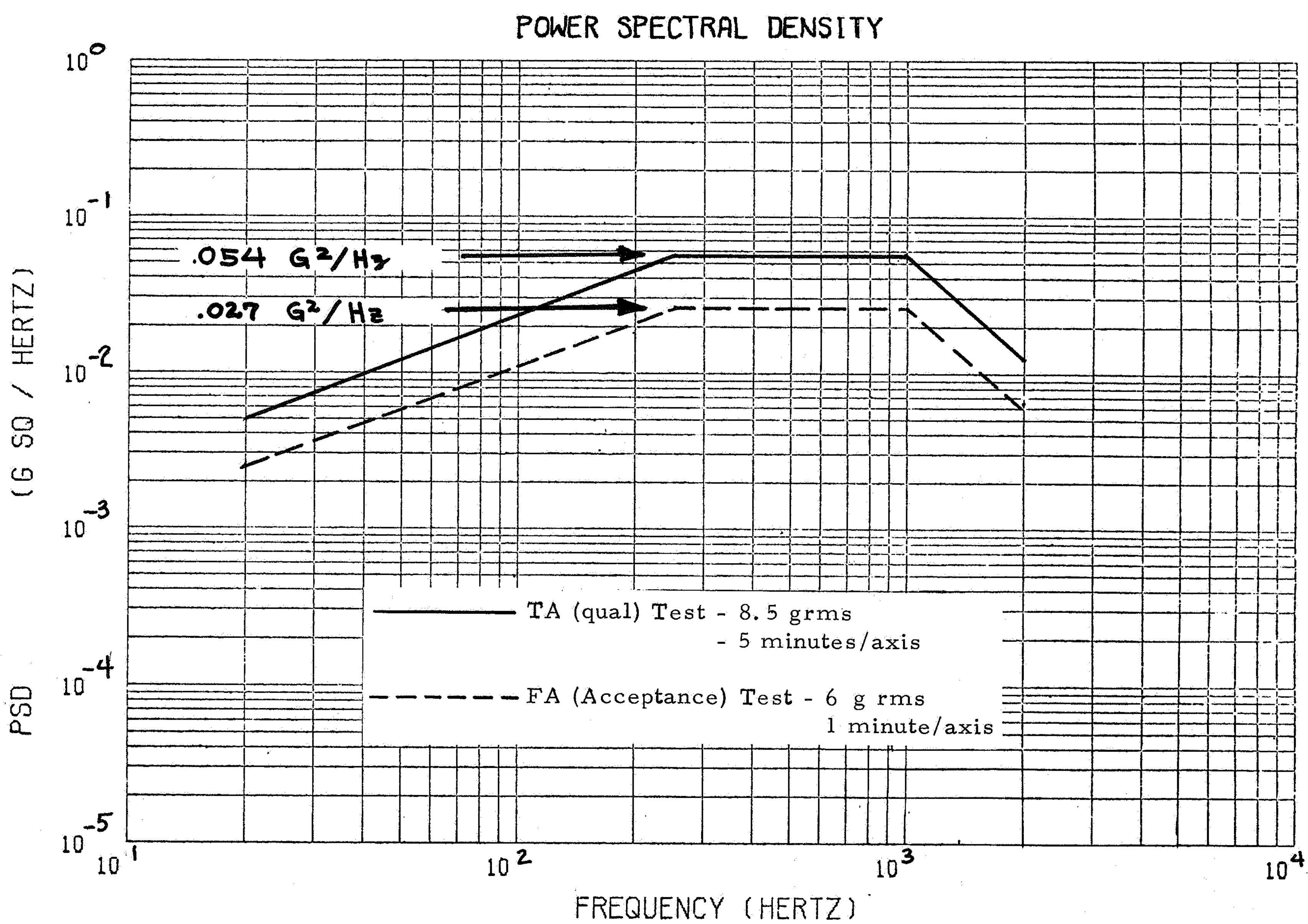


Figure 5.2.5 Viking Lander Capsule Component Random Vibration Test Minimum Requirement

5.3 Solid Rocket Motor (SRM) Ignition Overpressure Effect

Launch vehicle and spacecraft loads measurements made on Titan vehicles during SRM ignition and lift-off have been consistently higher than analytical predictions. Studies have led to the conclusion that SRM light off results in a pressure surge traveling up the launch vehicle inducing additional loads into the structure. However the actual characteristics of the pressure surge have not been quantified to permit an analytical treatment.

The acoustic measurements made on the four Titan Centaur flights have provided some new data on the characteristics of the pressure surge. The data presented here are time histories of acoustic vibration and strain measurement. The acoustic data show a consistency in a minus-plus-minus pressure fluctuation with similarity in wave shape. A tabulation of the times and magnitudes of these three initial peaks is shown in Table 5.3.1. The magnitude of the positive pressure (overpressure) is consistently the highest ranging from .04 to .14 psi. The period of the pressure pulse is in the 2.2 to 3.2 Hertz range.

Since the pressure wave is outside the Shroud and the acoustic sensors are all inside, Shroud attenuation must be accounted for in determining actual magnitudes of the pressure wave. That is the actual pressure surge acting on the external surfaces of the launch vehicle are larger than the pressure numbers shown in Table 5.3.1 by some factor which has not been determined. The transmission loss through the shroud in this frequency range is primarily a function of the stiffness of the shroud shell.

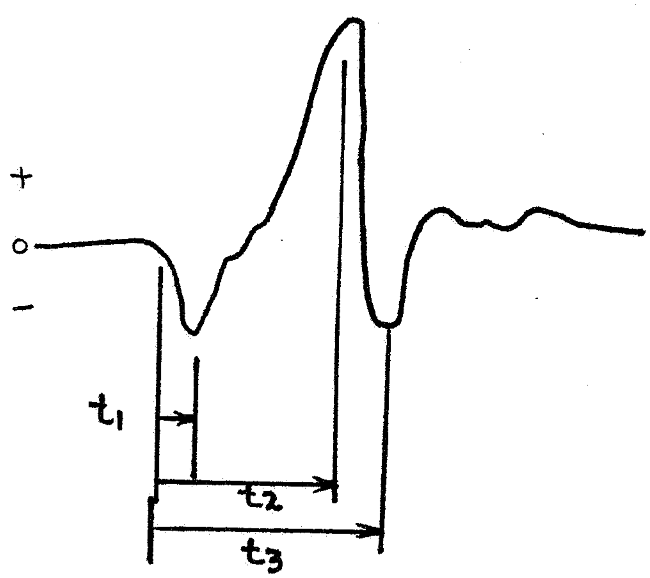
From the three microphones on the TC-2 flight it was possible to time the speed of travel of the pressure pulse. There was measured to be 20 milliseconds elapsed time between CA888Y and CA886Y and also between CA886Y and CY117Y. The distances between the microphones are 186 and 145 inches. Thus the approximate speed of travel of the pressure pulse is 690 feet per second.

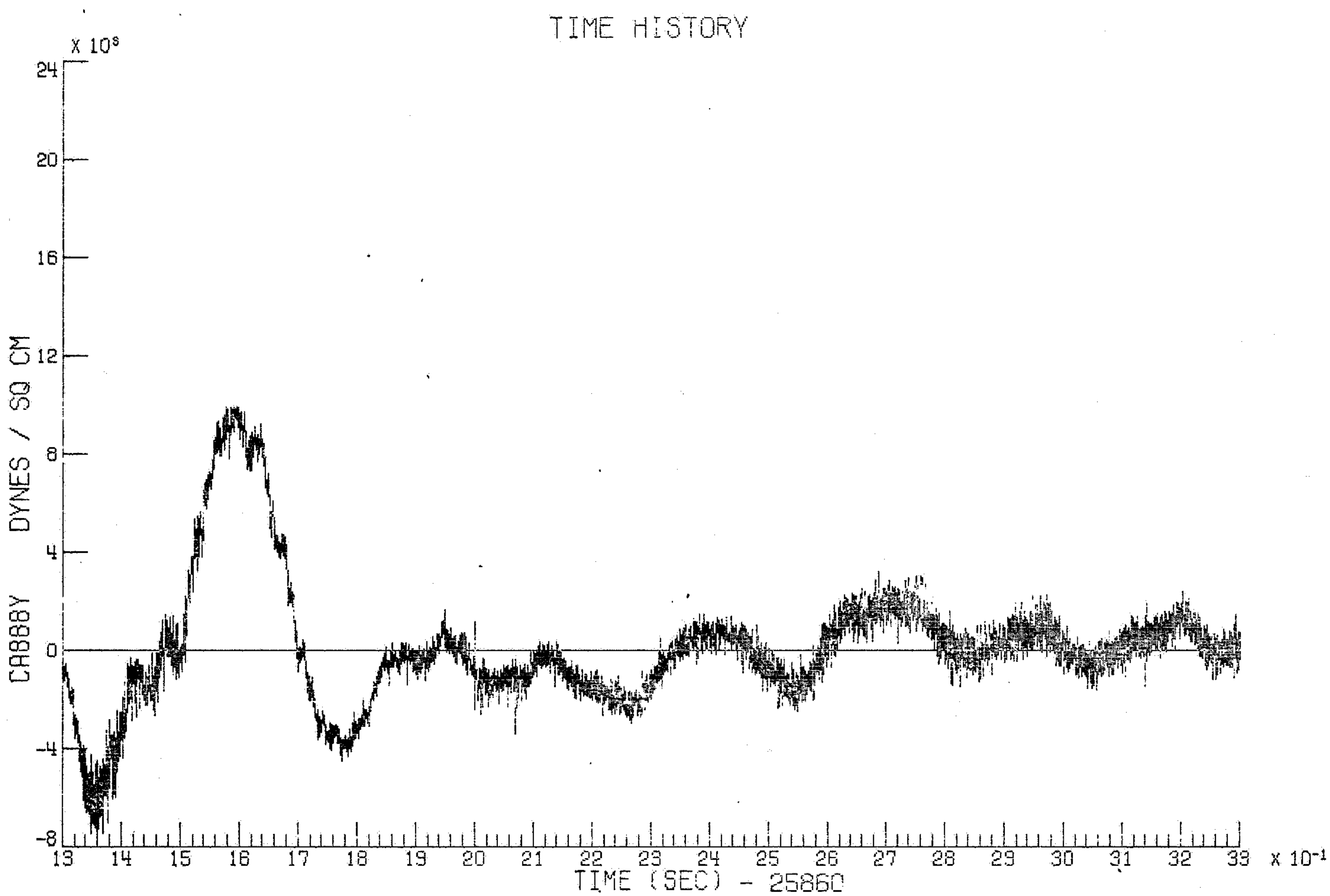
The pressure pulses measured on TC-4 and TC-3 differed from TC-1 and TC-2 in that the pressure pulse drop from plus to minus is much more abrupt. The sharpness of this pressure front is reflected in the vibration sensors as can be seen in Figures 5.3.6 and 5.3.8. In the period of time (10 to 20 ms) where the pressure drops from plus peak to minus peak there is a high frequency transient of short duration indicated by the vibration sensors.

Table 5.3.1 Stage 0 Ignition "Over Pressure"
(From Acoustic Measurements)

Flight & Sensor	Initial Pressure Drop (t_1) ms	psi	"Over-Pressure" (t_2) ms	psi	Pressure "Rebound" (t_3) ms	psi	Characteristic Period $1/(t_3 - t_1)$ Hertz
TC-1: CY117Y	50	-.032	390	.044	510	-.012	2.2
TC-2: GA1Y	120	-.047	360	.040	520	-.007	2.5
CA886Y	100	-.029	340	.049	500	-.009	2.5
CA888Y	80	-.089	320	.138	480	-.055	2.5
TC-4: CA886Y	40	-.058	300	.121	350	-.035	3.2
TC-3: CA886Y	50	-.061	280	.099	380	-.051	3.0

Typical Acoustic Pressure Oscillation



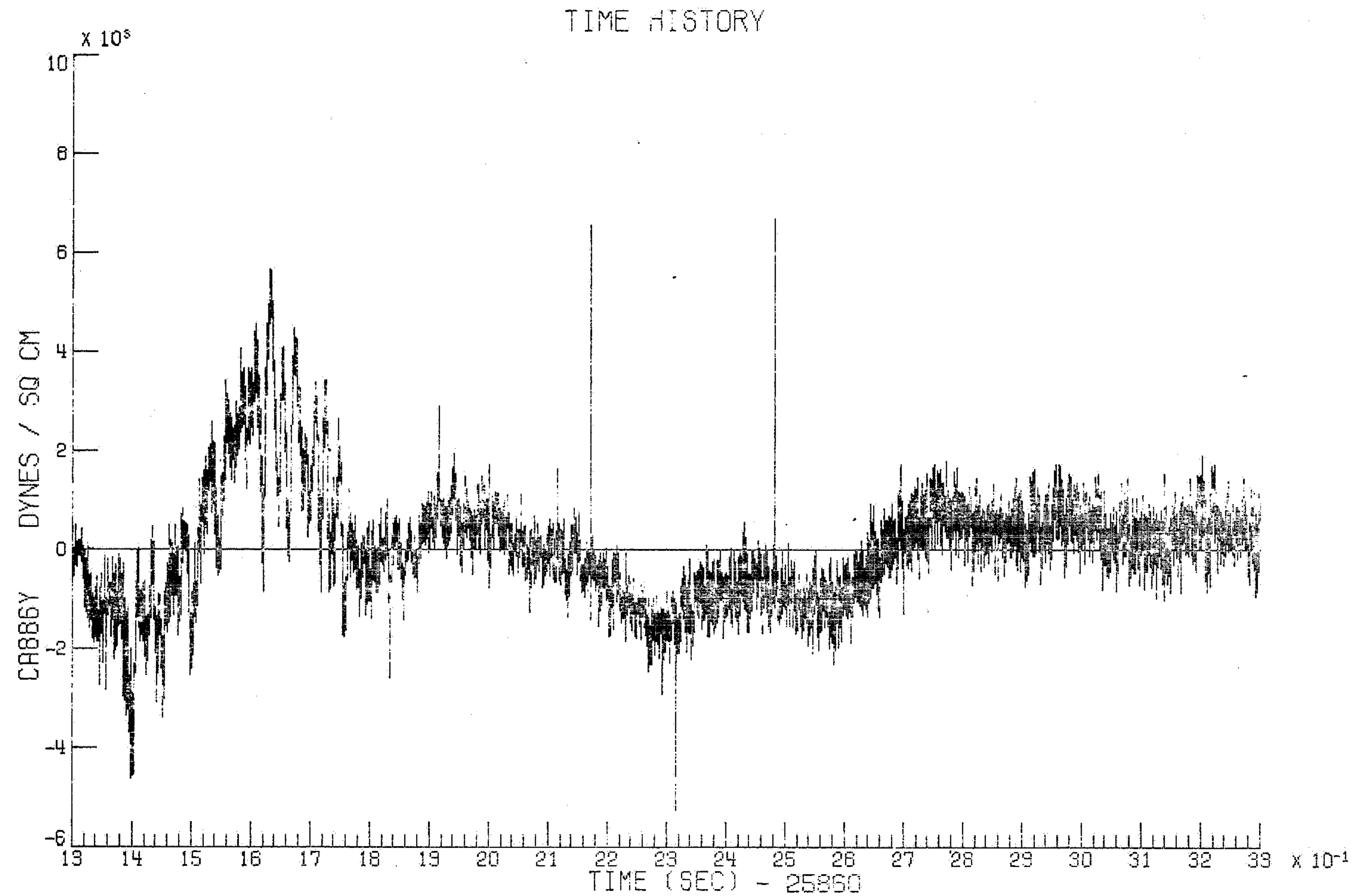


MAX = 9915.943 MIN = -7646.028

TC-2 ACOUSTIC STG 0 IGN / LIFT-OFF CA888Y

NASA-LANGLEY SIGNAL ANALYSIS PROGRAM 08/07/75

Figure 5.3.1



MAX = 6671.105 MIN = -5257.229

TC-2 ACOUSTIC STG 0 IGN / LIFT-OFF CA886Y

NASA-LANGLEY SIGNAL ANALYSIS PROGRAM 08/07/75

Figure 5.3.2

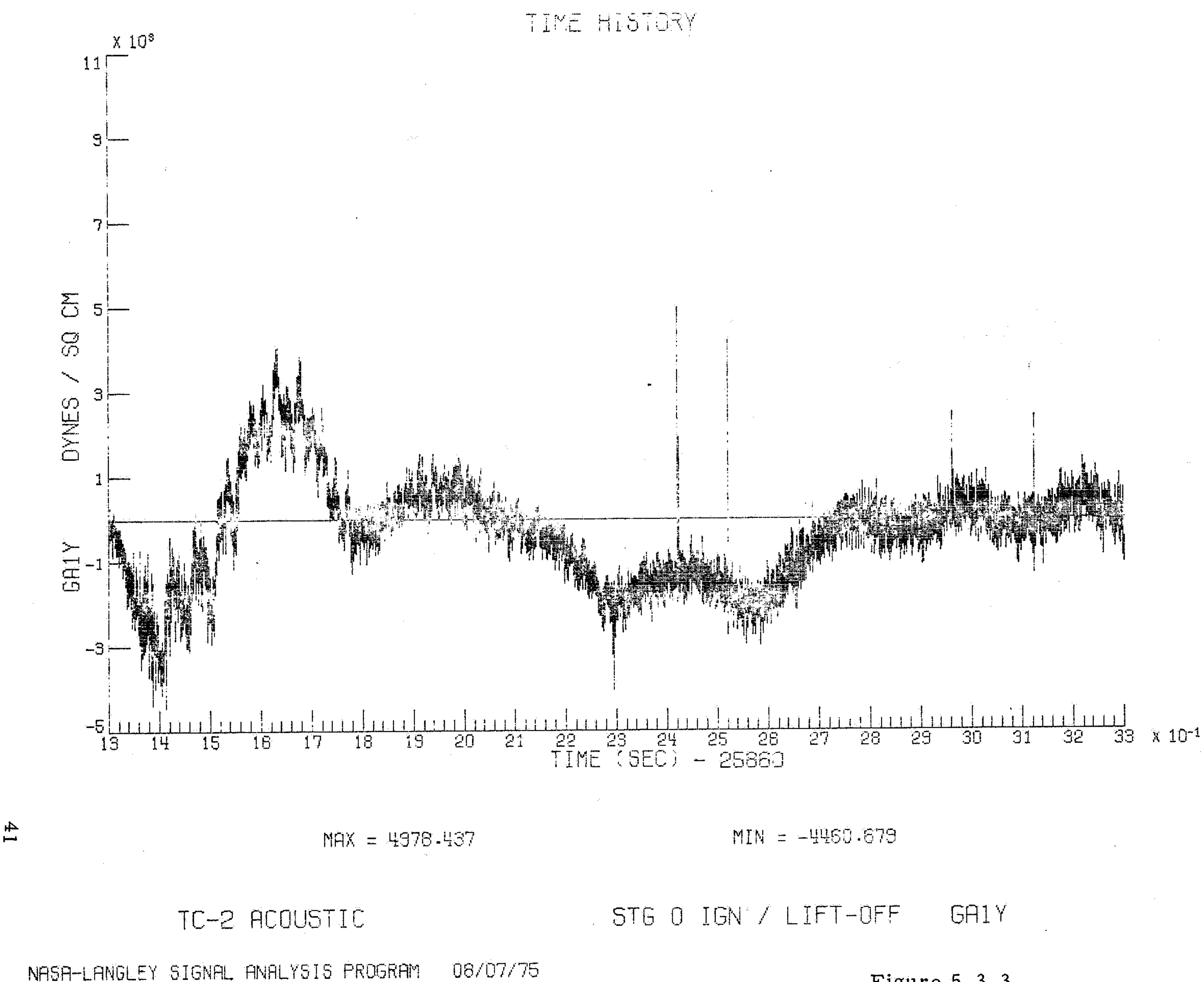

TIME HISTORY
X 10³
11
9
7
5
3
1
-1
-3
-5
DYNES / SQ CM
GA1Y
13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33
X 10⁻¹
TIME (SEC) - 25860
MAX = 4978.437
MIN = -4460.679
TC-2 ACOUSTIC
STG 0 IGN / LIFT-OFF GA1Y
NASA-LANGLEY SIGNAL ANALYSIS PROGRAM 08/07/75

Figure 5.3.3

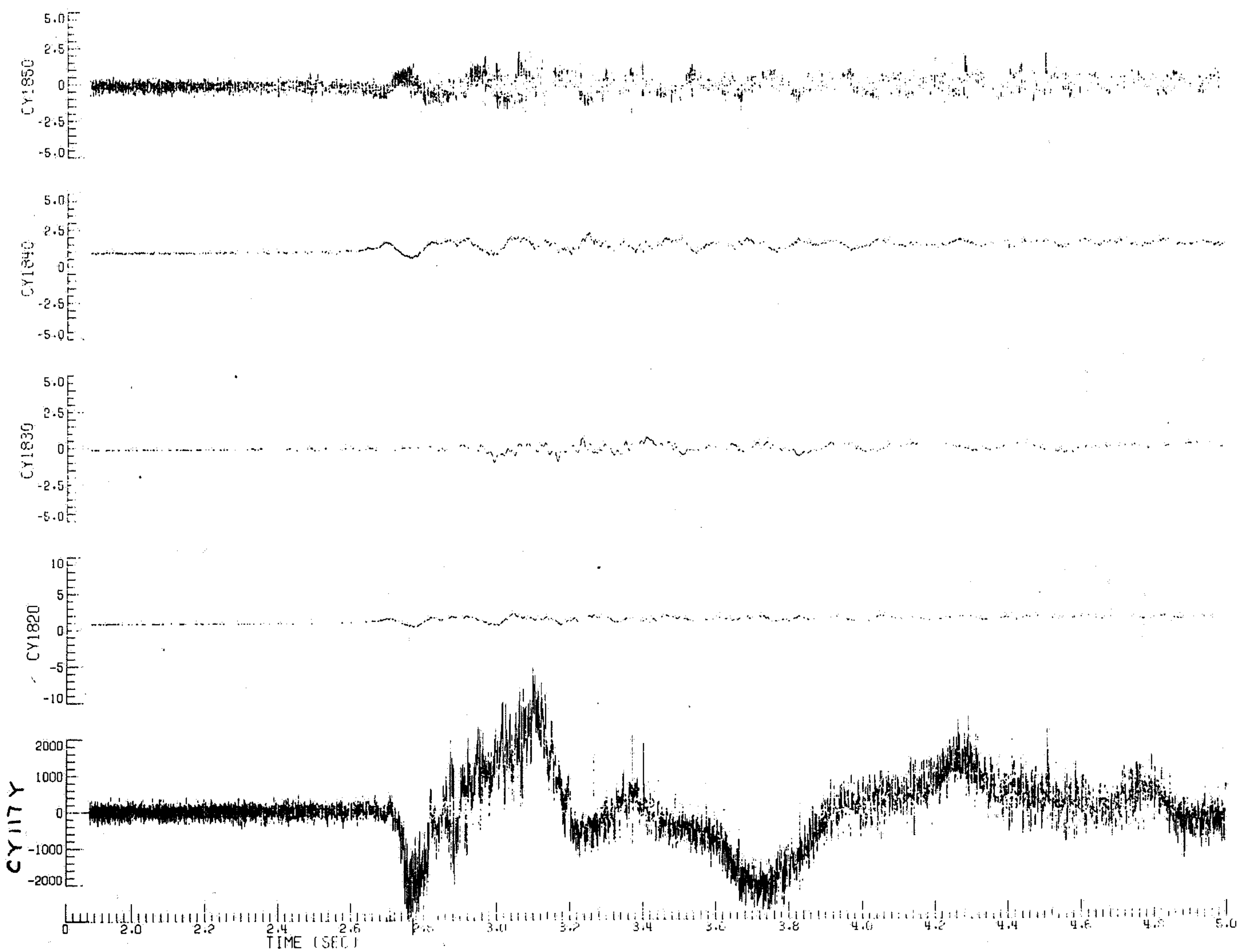


Figure 5.3.4 TC-1 Acoustic and Vibration Time Histories - Lift Off

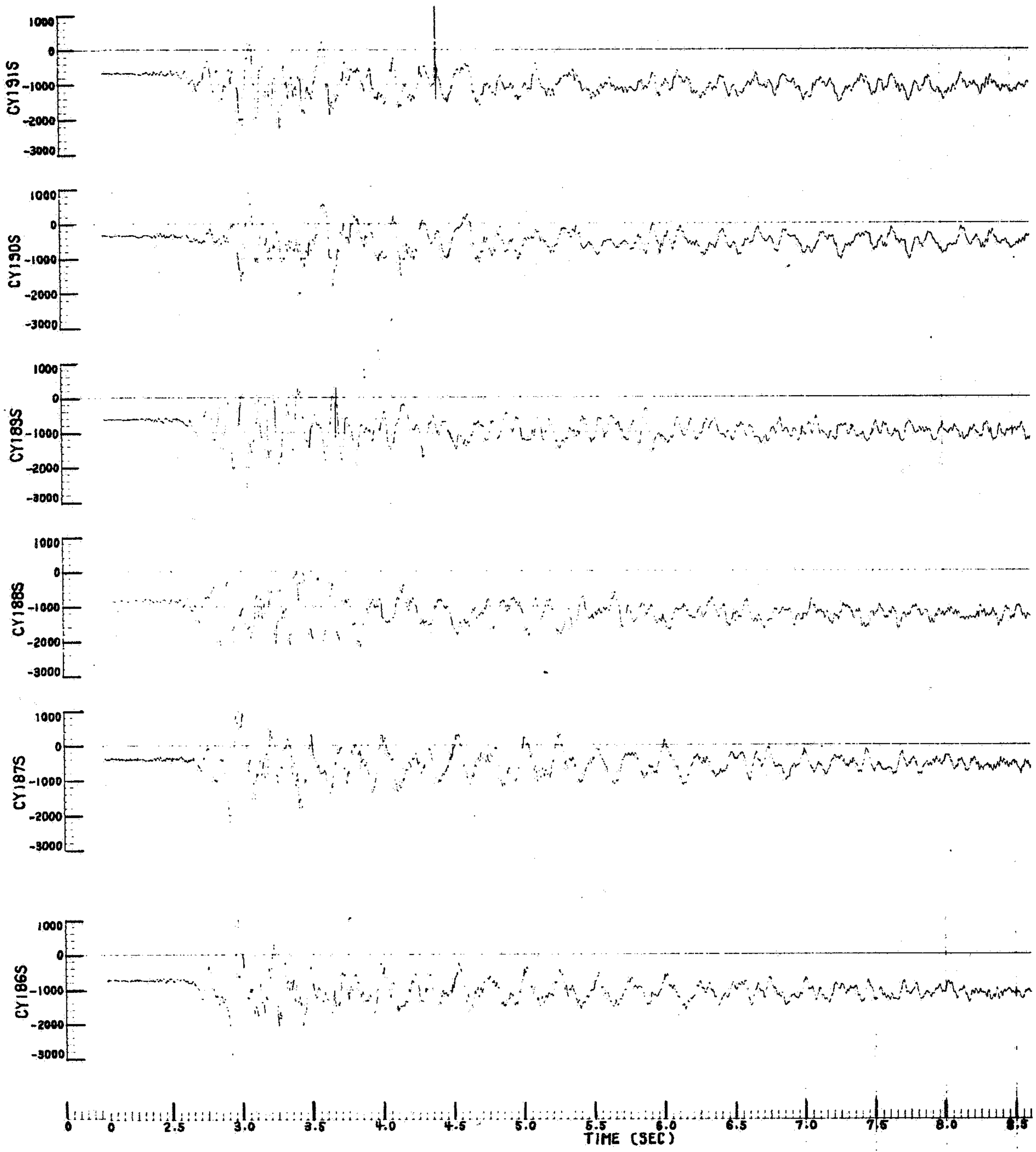


Figure 5.3.5 TC-1 Strain Time Histories, Lift Off

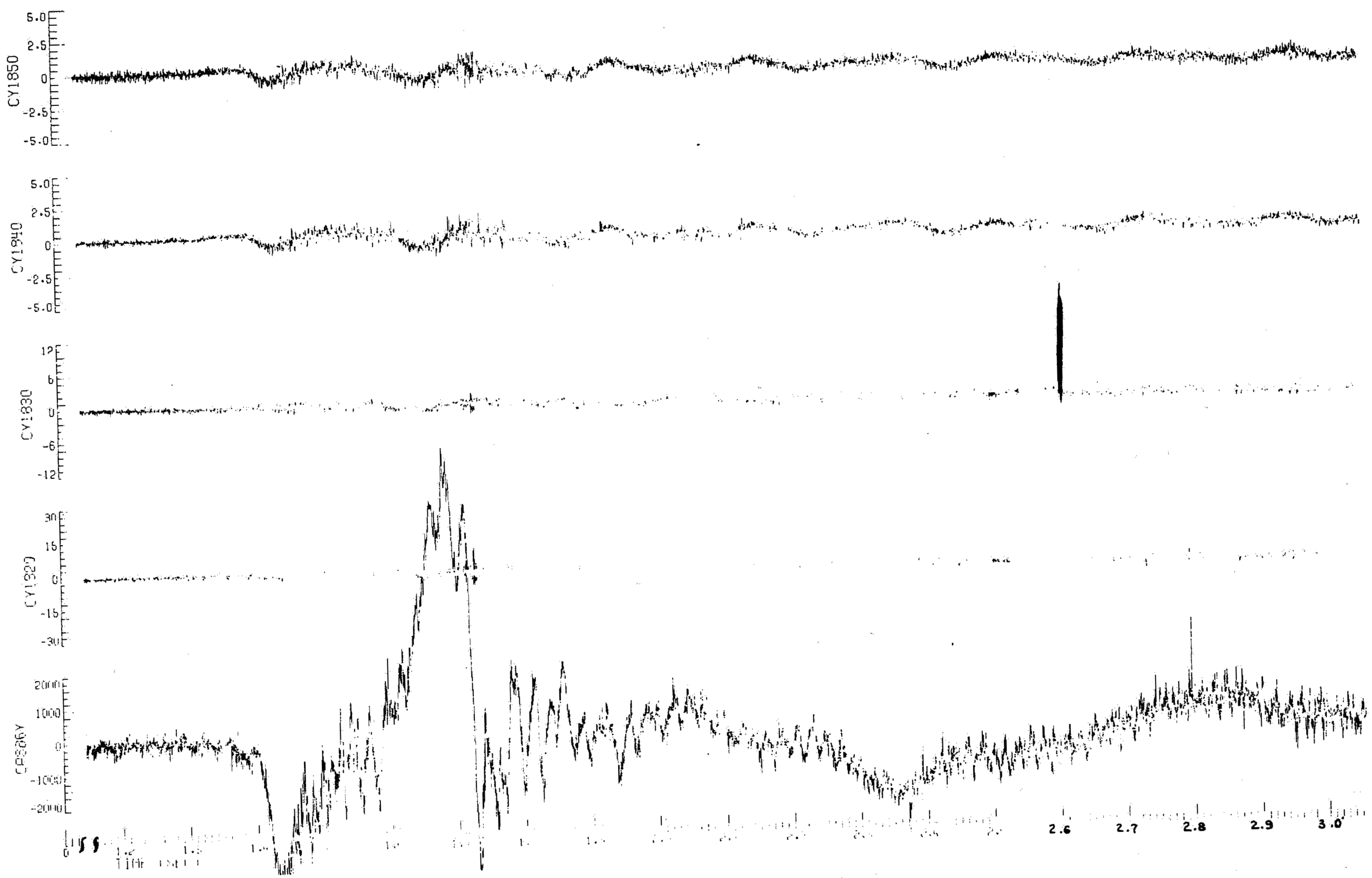


Figure 5.3.6 TC-4 Acoustic and Vibration Time Histories, Lift Off

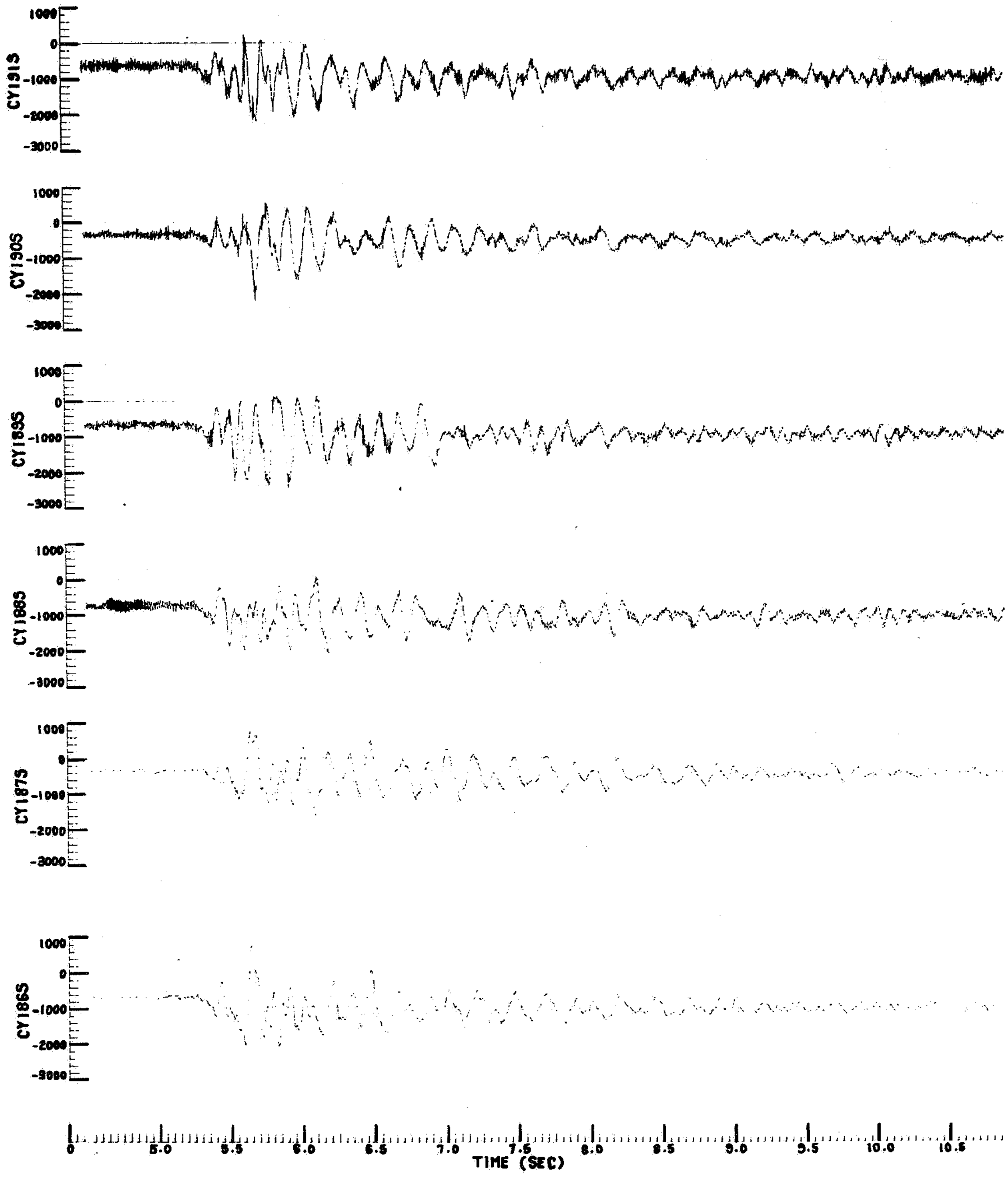


Figure 5.3.7 TC-4 Strain Time Histories, Lift Off

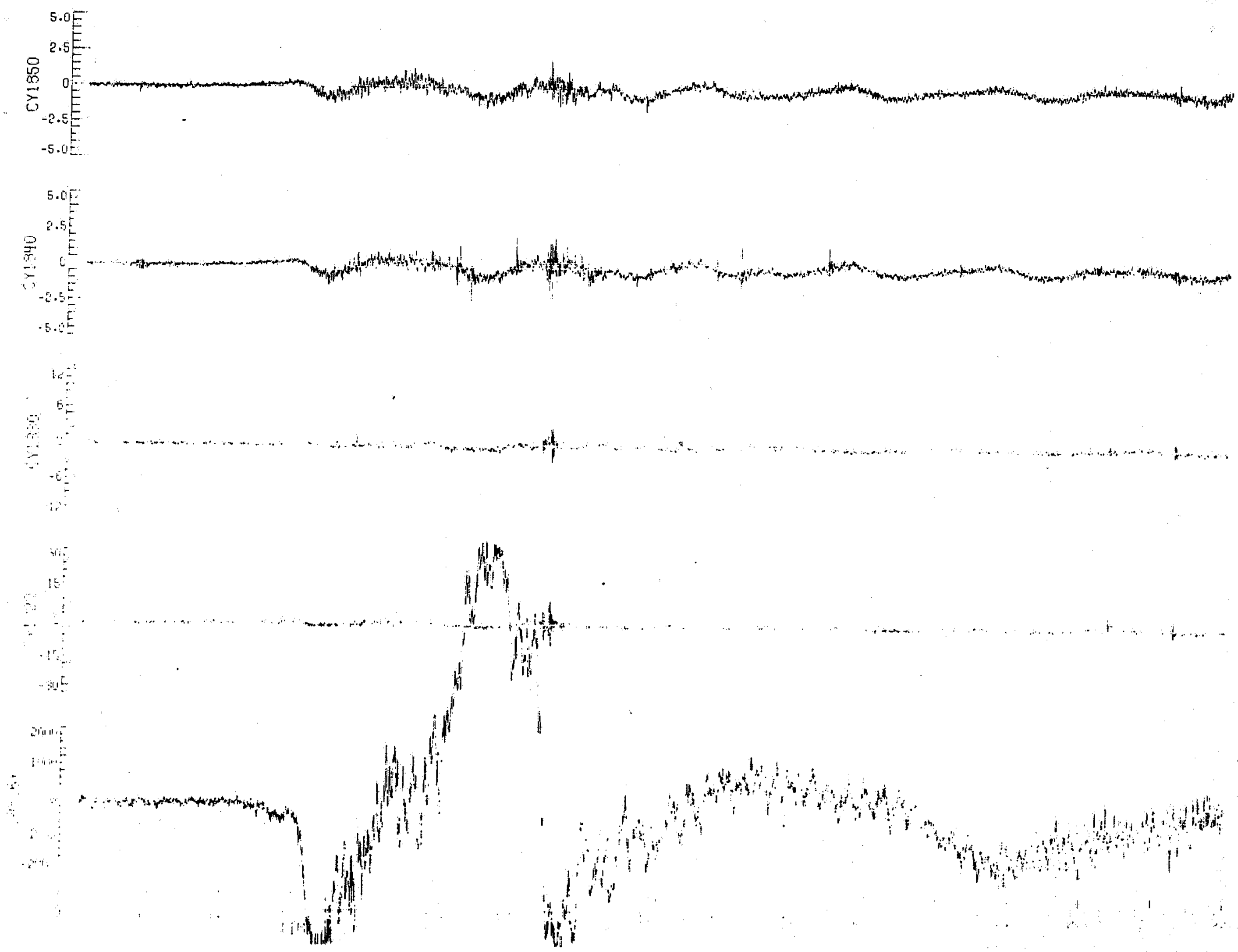


Figure 5.3.8 TC-3 Acoustic and Vibration Time Histories, Lift Off

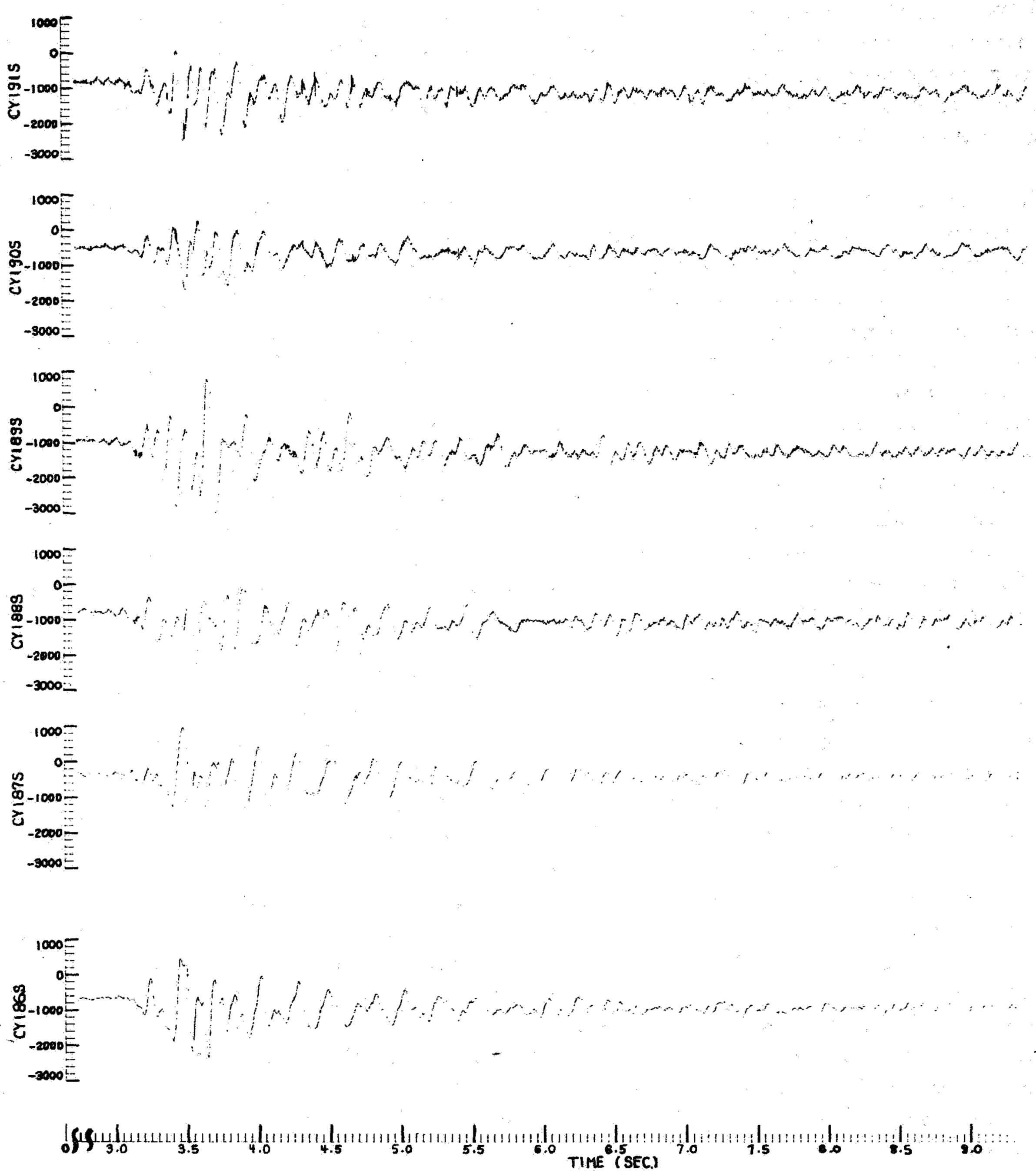


Figure 5.3.9 TC-3 Strain Time Histories, Lift Off

5.4 Shock Spectra - Mid Frequency Sine Test Comparison

Section 2 of this report presents an overview of the Viking Spacecraft dynamic environment divided into four frequency categories. The second of these four, the range between 30 and 200 Hertz, is the composite of the sixteen booster transients from Stage 0 Ignition through Spacecraft Separation and is referred to in this report as "Mid Frequency". The Mid-Frequency Sine Sweep Test for the Viking Spacecraft was devised as a simulation of this environment. The requirement and its development is presented in Reference 2.

The efforts of Reference 2 resulted in the criteria reproduced here in Figures 5.4.1 and 5.4.2. These criteria were based on a composite of response shock spectra gathered from available and applicable analytical and experimental data on booster transient events. Test techniques and environmental estimates are subject to uncertainties. In order to ensure that the sine test levels were conservative, these uncertainties were identified and an estimate of the degree of uncertainty calculated. The most probable uncertainty (error) was estimated by the root sum square (RSS) of individual uncertainties where they were identified as independent random variables. The resulting most probable uncertainty was applied to the composite shock spectrum, as shown in Figure 5.4.1 and a straight line envelope "test level" was drawn. Figure 5.4.2 revises this envelope by the Q factor to define the Flight Acceptance (FA) test level and the 50% higher Type Approval (TA) test level.

Referring back to Table 2.2 it is seen that the low frequency component of the Booster transients are defined by dynamic loads analyses of the specific spacecraft configurations. The nature of the resulting loads are such that qualification testing is best done through structural loadings of structural assemblies. Further, in this frequency range, 0-30 Hertz, the sine testing defined would probably result in loads which exceed the design load conditions. This situation is due primarily to the ground test boundary conditions being different from flight boundary conditions on the spacecraft. In light of this it was necessary to monitor response loads on the spacecraft structures and to limit test inputs so that structure design loads were not exceeded in the frequency range below 30 Hz. Figures 5.4.3 and 5.4.4 show plots of the specification test inputs superimposed on the actual test input levels where load limiting was enforced with automatic test control equipment. It is seen that for both the Viking Lander Capsule (VLC), Figure 5.4.3 and the Viking Orbiter (VO), Figure 5.4.4, the input is actually notched in the 10 to 30 Hertz range.

A comparison of flight measurements against ground test responses is shown in Figures 5.4.5 through 5.4.9. The data shows that in general the flight measurements fall below the Viking test requirements with satisfactory margins. The exceptions will now be discussed.

In Figures 5.4.5 and 5.4.8 the flight levels exceed the test levels in the 10-30 Hertz range when the test was notched by load limiting. However the exceedance is due in whole to the data from the TC-1 Stage 1 Burn Out condition. A review of the TC-1 data analysis did not uncover any suspected sources of error. However there is a difference in damping between the TC-1 and TC-4 & 3 spacecraft (about 1:5) which could explain the difference in the shock spectra (about 1:3). It was therefore concluded that the broken line in Figures 5.4.5 and 5.4.8 are representative of very lightly damped spacecraft ($\approx$ 0.2% of critical) and the solid lines are more representative of spacecraft with modal damping of 1% or greater.

In Figure 5.4.6 the flight data above 40 Hertz is equal to or greater than comparable ground test measurements. This flight data was the result of transformation of VLCA strain measurements to VLC cg accelerations. The phase error in the data playback of the strain data was less than ± 1.0 degrees at 60 Hertz, less than ± 4 degrees at 90 Hertz and increased fairly rapidly above 100 Hertz. Consequently the strain data is valid to 60 Hertz and begins to lose accuracy above that. However the transformation used to obtain VLC cg accelerations from the strain data assumes a rigid lander. Because of this the flight data is in error above 40 Hertz and would result in readings which are too high as is indicated.

A final observation is made that the oscillations experienced during Titan Stage 1 Burn and Centaur First Burn in the TC-4 and TC-3 flights were within the test levels performed on Viking. The TC-1 and TC-2 Stage 1 Burn oscillation exceeded the Viking test levels. However the Stage 1 propulsion system was modified after the TC-1 and again after TC-2 to improve Stage 1 Burn conditions. This is discussed in a little more detail in section 5.5.

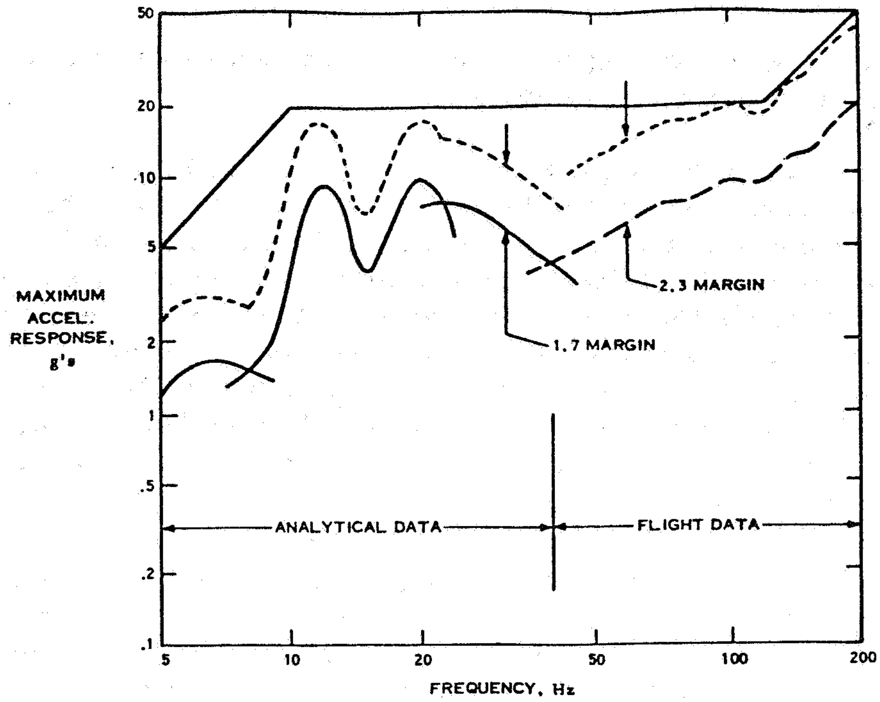


Figure 5.4.1 Determination of Mid Frequency Test Levels

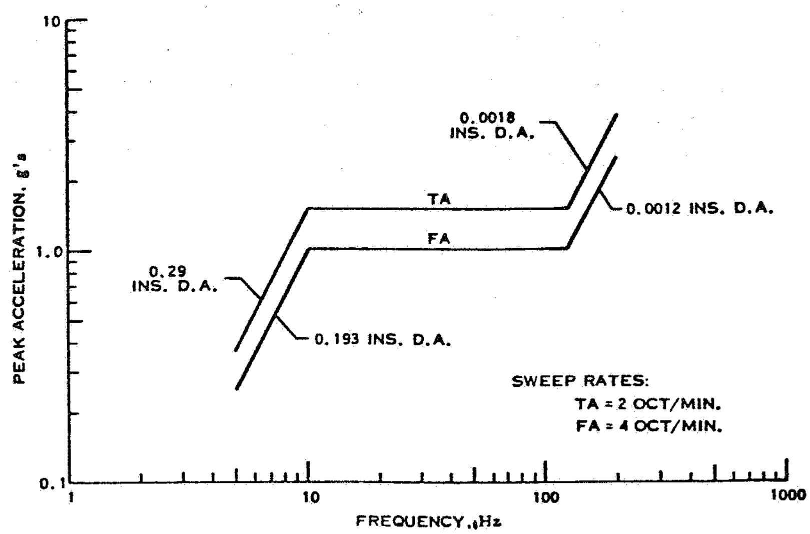


Figure 5.4.2 Mid Frequency Sine Test Levels, Viking Program

FIGURE 5.4.3

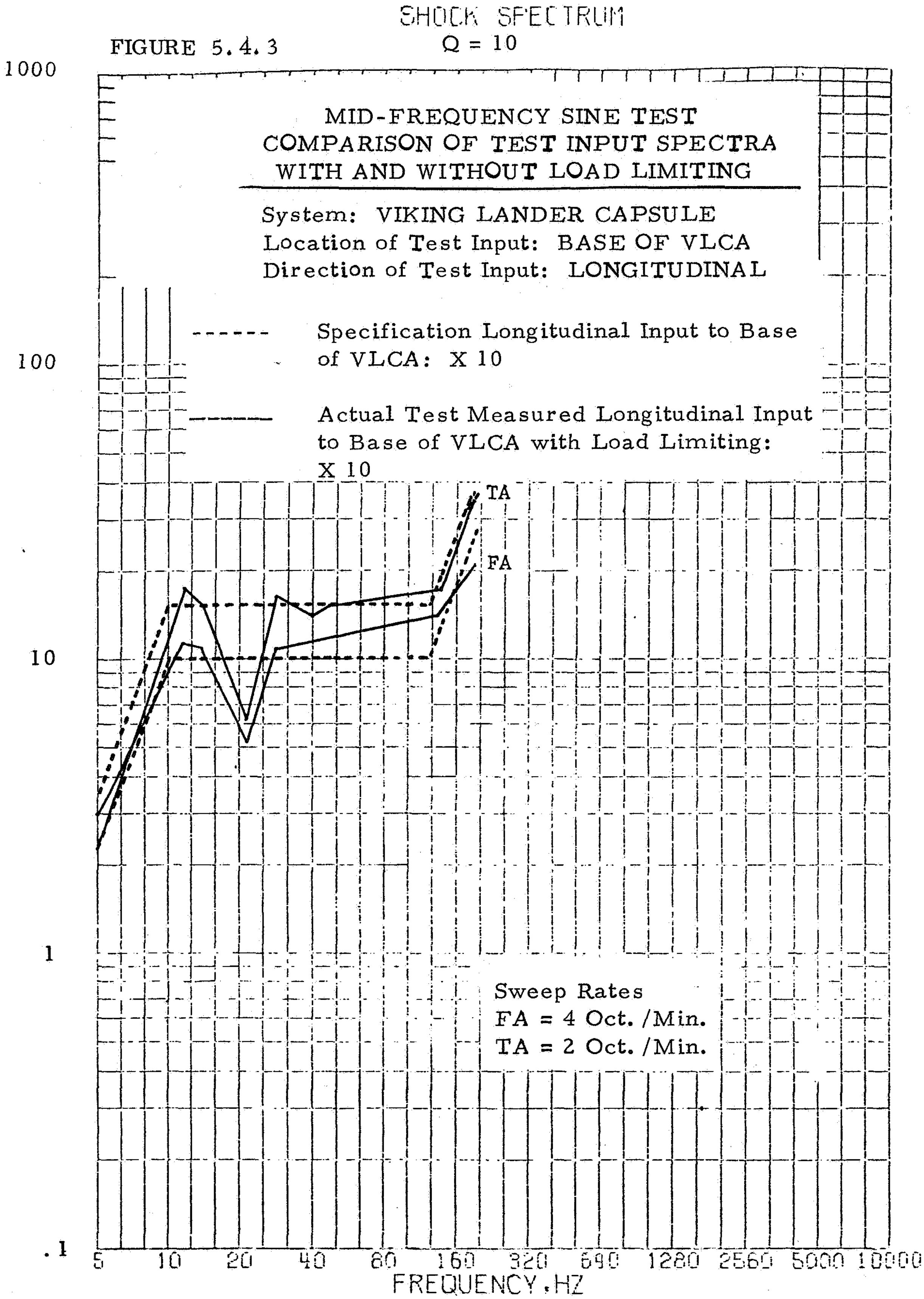

SHOCK SPECTRUM
Q = 10
MID-FREQUENCY SINE TEST
COMPARISON OF TEST INPUT SPECTRA
WITH AND WITHOUT LOAD LIMITING
System: VIKING LANDER CAPSULE
Location of Test Input: BASE OF VLCA
Direction of Test Input: LONGITUDINAL
Specification Longitudinal Input to Base of VLCA: X 10
Actual Test Measured Longitudinal Input to Base of VLCA with Load Limiting: X 10
TA
FA
Sweep Rates
FA = 4 Oct. /Min.
TA = 2 Oct. /Min.
1000
100
10
1
.1
5
10
20
40
80
160
320
640
1280
2560
5000
10000
FREQUENCY, HZ

FIGURE 5.4.4

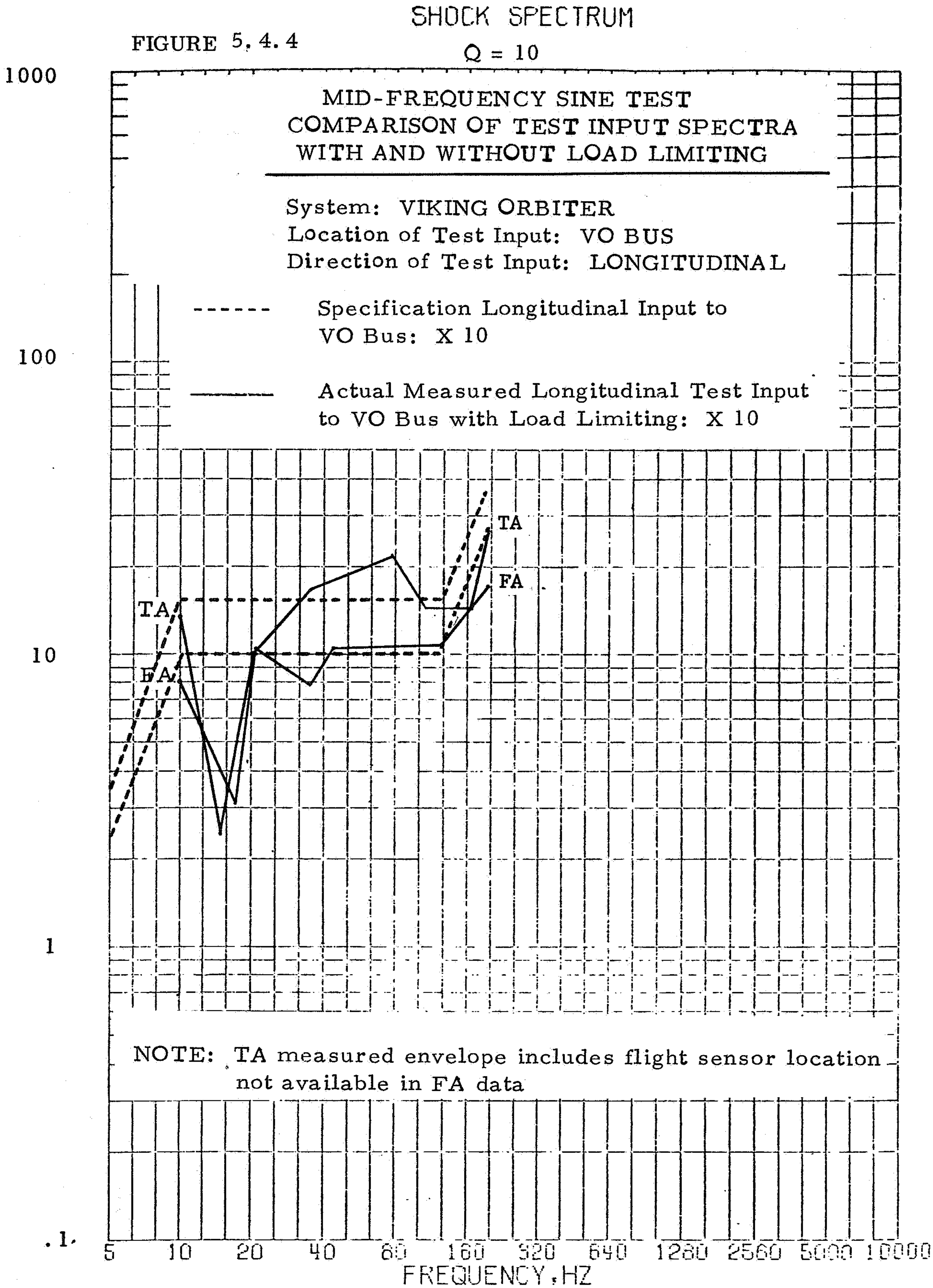

SHOCK SPECTRUM
Q = 10
MID-FREQUENCY SINE TEST
COMPARISON OF TEST INPUT SPECTRA
WITH AND WITHOUT LOAD LIMITING
System: VIKING ORBITER
Location of Test Input: VO BUS
Direction of Test Input: LONGITUDINAL
------ Specification Longitudinal Input to VO Bus: X 10
——— Actual Measured Longitudinal Test Input to VO Bus with Load Limiting: X 10
TA
FA
TA
FA
NOTE: TA measured envelope includes flight sensor location not available in FA data
1000
100
10
1
.1
5
10
20
40
80
160
320
640
1280
2560
5000
10000
FREQUENCY, HZ

FIGURE 5.4.5

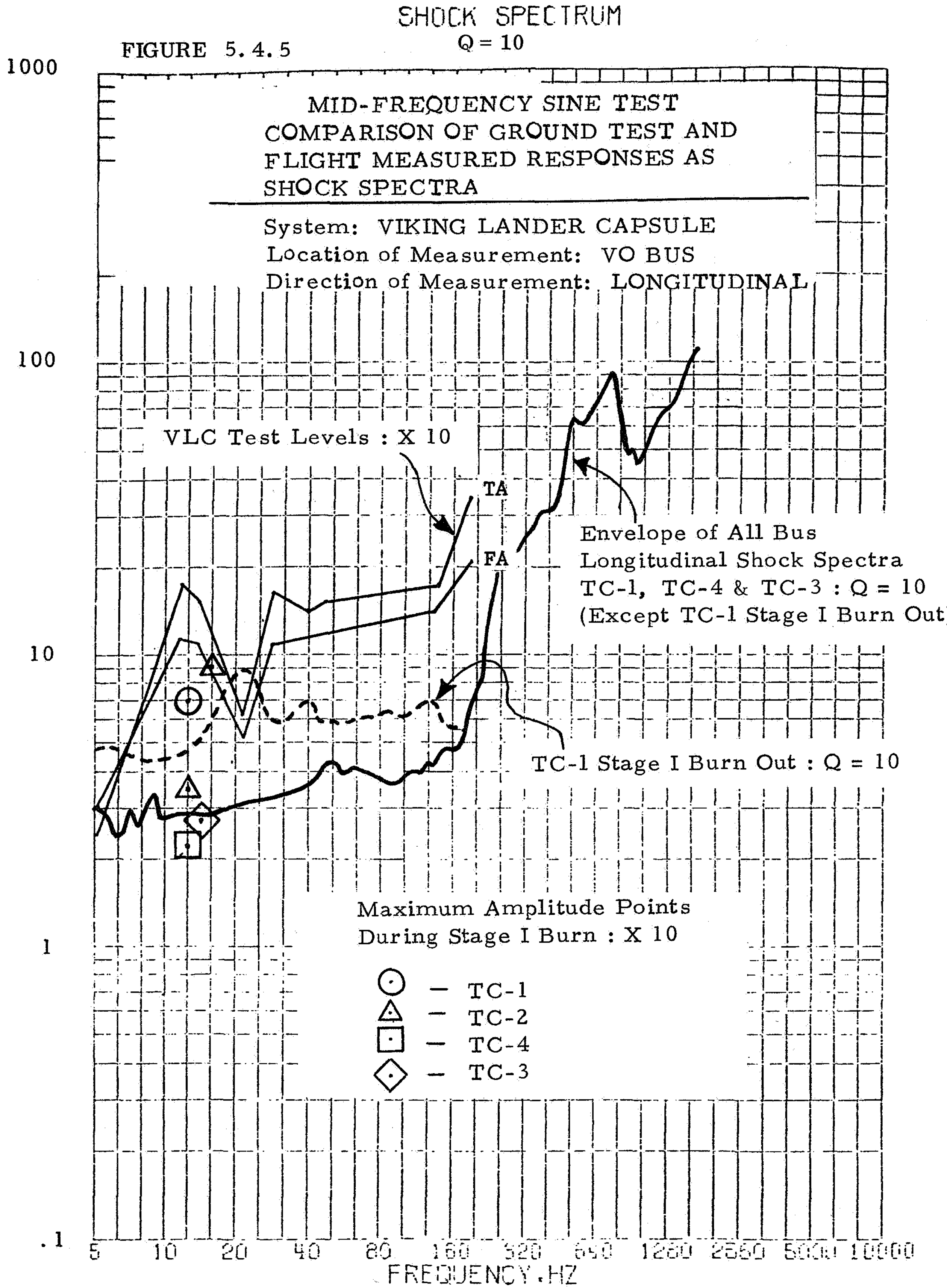
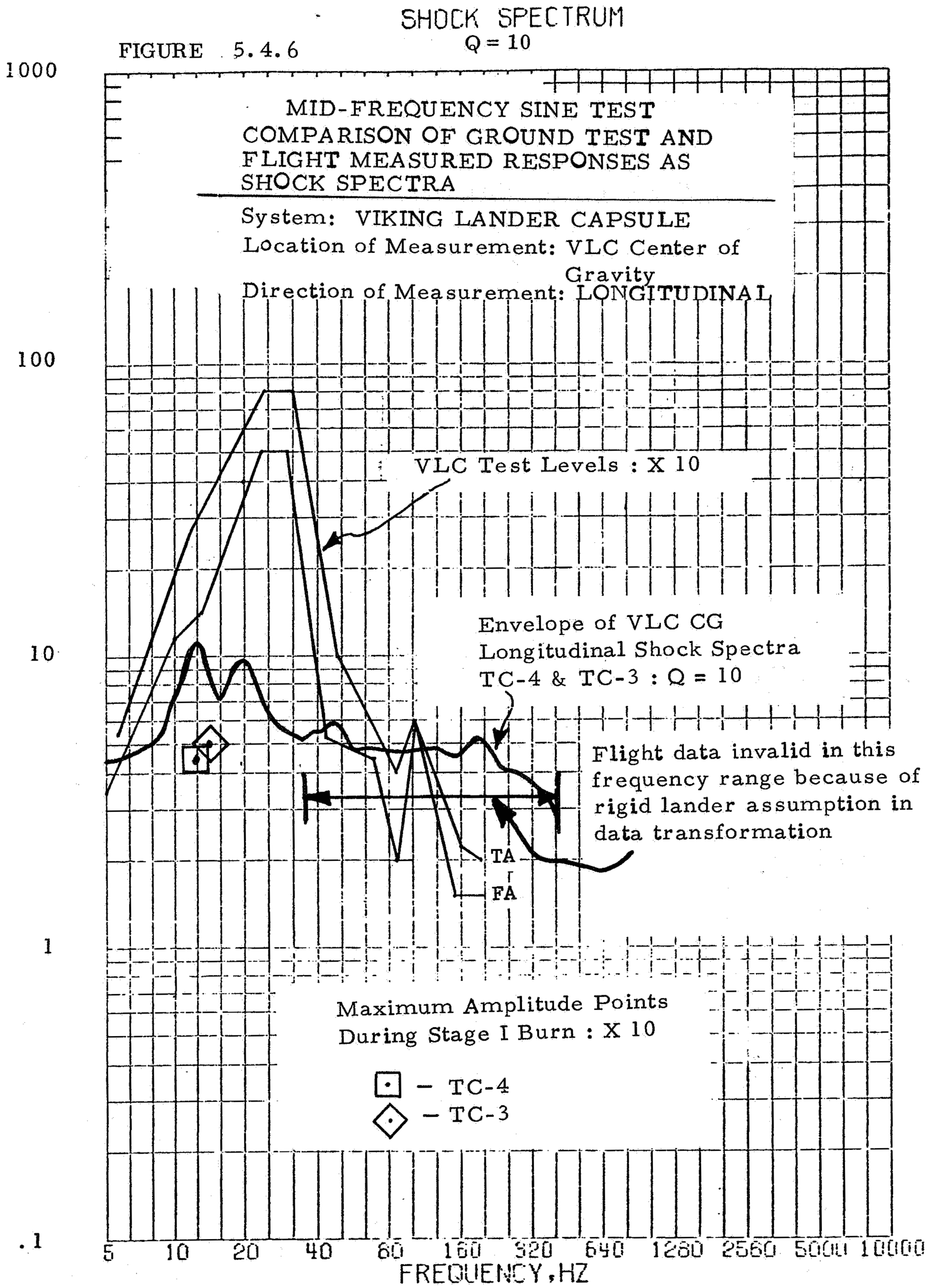

SHOCK SPECTRUM
Q = 10
MID-FREQUENCY SINE TEST
COMPARISON OF GROUND TEST AND
FLIGHT MEASURED RESPONSES AS
SHOCK SPECTRA
System: VIKING LANDER CAPSULE
Location of Measurement: VO BUS
Direction of Measurement: LONGITUDINAL
1000
100
10
1
.1
VLC Test Levels : X 10
TA
FA
Envelope of All Bus
Longitudinal Shock Spectra
TC-1, TC-4 & TC-3 : Q = 10
(Except TC-1 Stage I Burn Out)
TC-1 Stage I Burn Out : Q = 10
Maximum Amplitude Points
During Stage I Burn : X 10
— TC-1
— TC-2
— TC-4
— TC-3
5
10
20
40
80
160
320
640
1280
2560
5000
10000
FREQUENCY, HZ

FIGURE 5.4.6



SHOCK SPECTRUM
Q = 10
MID-FREQUENCY SINE TEST
COMPARISON OF GROUND TEST AND FLIGHT MEASURED RESPONSES AS SHOCK SPECTRA
System: VIKING LANDER CAPSULE
Location of Measurement: VLC Center of Gravity
Direction of Measurement: LONGITUDINAL
VLC Test Levels : X 10
Envelope of VLC CG Longitudinal Shock Spectra TC-4 & TC-3 : Q = 10
Flight data invalid in this frequency range because of rigid lander assumption in data transformation
TA
FA
Maximum Amplitude Points During Stage I Burn : X 10
– TC-4
– TC-3
1000
100
10
1
.1
5
10
20
40
80
160
320
640
1280
2560
5000
10000
FREQUENCY, HZ

FIGURE 5.4.7

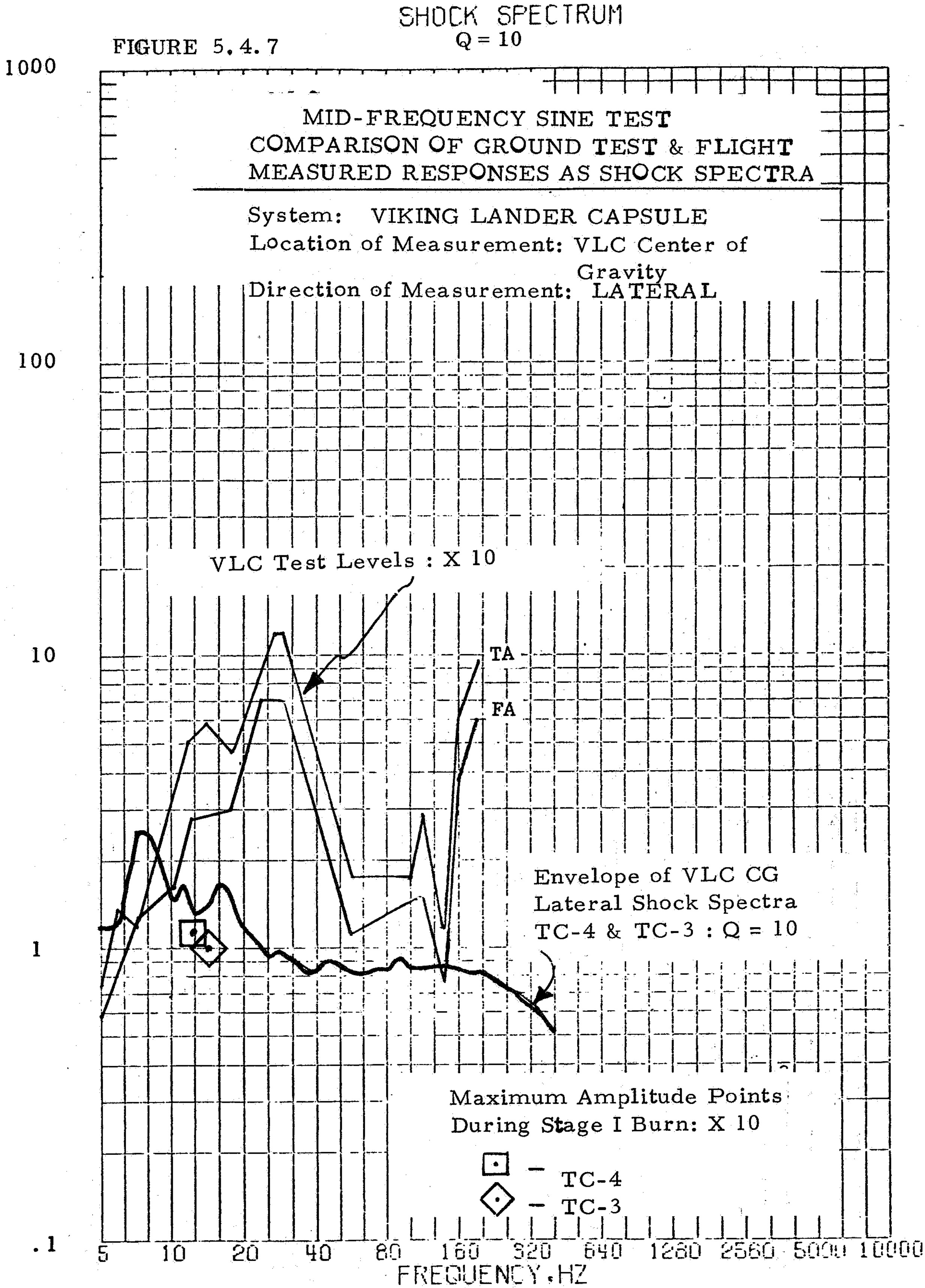

SHOCK SPECTRUM
Q = 10
MID-FREQUENCY SINE TEST
COMPARISON OF GROUND TEST & FLIGHT
MEASURED RESPONSES AS SHOCK SPECTRA
System: VIKING LANDER CAPSULE
Location of Measurement: VLC Center of Gravity
Direction of Measurement: LATERAL
VLC Test Levels : X 10
TA
FA
Envelope of VLC CG
Lateral Shock Spectra
TC-4 & TC-3 : Q = 10
Maximum Amplitude Points
During Stage I Burn: X 10
– TC-4
– TC-3
1000
100
10
1
.1
5
10
20
40
80
160
320
640
1280
2560
5000
10000
FREQUENCY, HZ

FIGURE 5.4.8

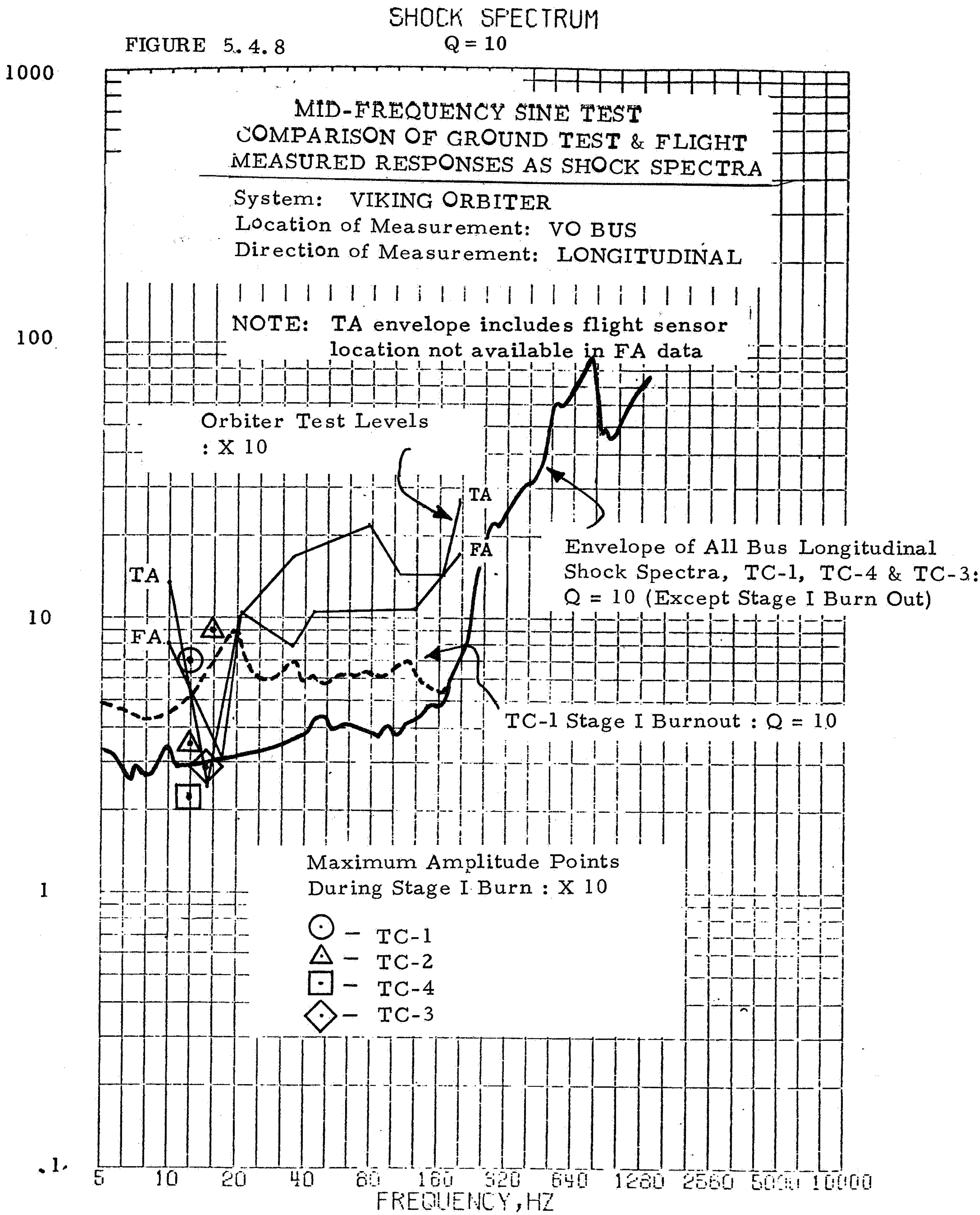
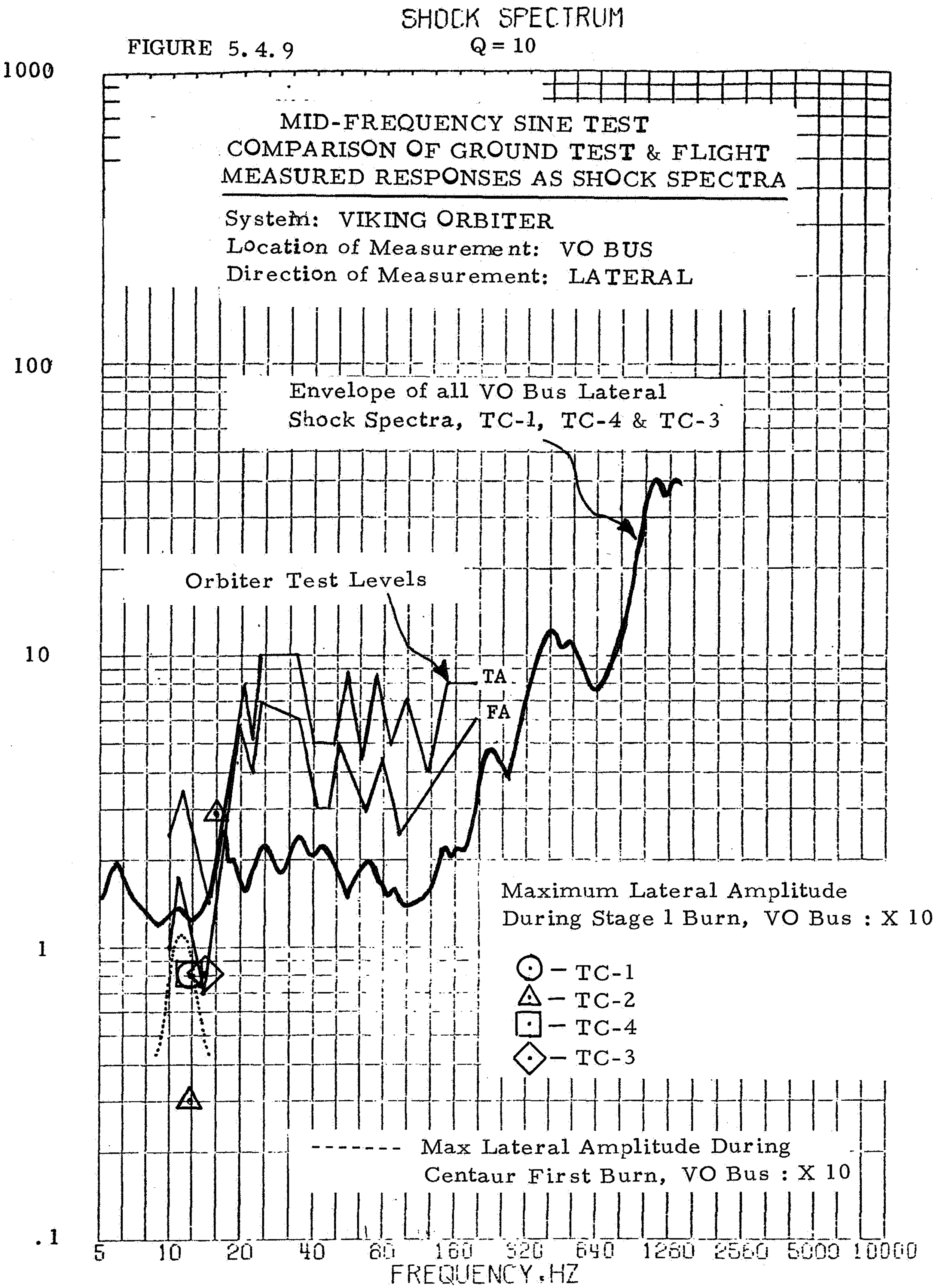

SHOCK SPECTRUM
Q = 10
MID-FREQUENCY SINE TEST
COMPARISON OF GROUND TEST & FLIGHT
MEASURED RESPONSES AS SHOCK SPECTRA
System: VIKING ORBITER
Location of Measurement: VO BUS
Direction of Measurement: LONGITUDINAL
NOTE: TA envelope includes flight sensor location not available in FA data
Orbiter Test Levels
: X 10
TA
FA
TA
FA
Envelope of All Bus Longitudinal Shock Spectra, TC-1, TC-4 & TC-3: Q = 10 (Except Stage I Burn Out)
TC-1 Stage I Burnout : Q = 10
Maximum Amplitude Points
During Stage I Burn : X 10
— TC-1
— TC-2
— TC-4
— TC-3
1000
100
10
1
.1
5
10
20
40
80
160
320
640
1280
2560
5000
10000
FREQUENCY, HZ

FIGURE 5.4.9


SHOCK SPECTRUM
Q = 10
MID-FREQUENCY SINE TEST
COMPARISON OF GROUND TEST & FLIGHT
MEASURED RESPONSES AS SHOCK SPECTRA
System: VIKING ORBITER
Location of Measurement: VO BUS
Direction of Measurement: LATERAL
Envelope of all VO Bus Lateral
Shock Spectra, TC-1, TC-4 & TC-3
Orbiter Test Levels
TA
FA
Maximum Lateral Amplitude
During Stage 1 Burn, VO Bus : X 10
— TC-1
— TC-2
— TC-4
— TC-3
------- Max Lateral Amplitude During
Centaur First Burn, VO Bus : X 10
1000
100
10
1
.1
5
10
20
40
80
160
320
640
1280
2560
5000
10000
FREQUENCY, HZ

5.5 POGO, FLMN and Centaur Burn Oscillations

The objective followed in this section is to quantify the experience of powered flight oscillations on TC-1, TC-2, TC-3 and TC-4 without addressing the problem of determining cause and effect. The definition of POGO, FLMN and Centaur Burn Oscillations as used here are as follows:

> POGO is defined as the longitudinal oscillations in the first longitudinal mode of the Launch Vehicle which are experienced during Titan Stage 1 burn and where a limit cycle type coupling is inferred to exist between the propulsion system dynamics and the L/V structure dynamics.
>
> FLMN is the acronym for First Longitudinal Mode Noise and is distinguished from POGO in that it is the random response, in the first mode to thrust roughness of a stable system.
>
> Centaur Burn Oscillations are structural vibrations during Centaur First Burn which seem to be predominantly in the fundamental lateral bending modes of the space vehicle configuration. Although there is a coupling with the lateral resonance of the thrusters there was apparently no evidence of feedback or a control system stability problem.

There were changes made to the Titan Stage 1 propulsion system which had apparent effects on the longitudinal oscillations. The differences in configuration are listed below as a matter of information, again with no attempt to explain or connect cause and effect.

Stage 1 Propulsion System Configuration

Launch Vehicle	Superheaters	Oxidizer Accumulator
TC-1	2	0
TC-2	1	0
TC-3 & 4	2	2

Summary of Stage 1 Data

Table 5.5.1 presents a summary of the maximum amplitudes experienced in the four launchings. The frequency of the maximum oscillations are also plotted in Figure 5.5.1 showing relationship to the analytically determined first longitudinal mode frequency. Figures 5.5.2 through 5.5.5 show the variation of steady state acceleration and acceleration amplitude of the first longitudinal mode throughout Stage 1 Burn for each of the four flights.

When compared to the Viking midfrequency sine test requirement, on the shock spectrum plots of Figures 5.5.6 and 5.5.7, the flight experience was covered in the VLC testing and was not covered in the VO test. The difference in the VLC and VO testing was in the details of response load limits. If the TC-1 and TC-2 flight experiences of POGO/FLMN are eliminated as not valid design criteria for the final Titan IIIE configuration then the VO testing also covers the flight levels; i.e. the TC-4 and TC-3 experience.

However the longitudinal oscillations experienced are of high enough amplitudes even on TC-4 and TC-3 that a POGO/FLMN design loads requirement should be defined for future Titan Centaur launch vehicles. Further, with the complexity of the analytical processes for predicting this type of loading some relatively large uncertainty factor should be used.

An envelope of PSD analyses from TC-4 and TC-3 is shown in Figure 5.5.8. Maximum values are seen to occur in the 12-14 Hertz frequency range.

Centaur Burn Oscillations

The oscillations during the first burning of the Centaur Main Engine followed the same pattern in TC-4 and TC-3 of reaching maximum acceleration amplitude within five seconds after steering start and then gradually decreasing in amplitude. The motions are barely detectable at the VO Bus, and are largest in lateral motions at the VLC cg. VLC cg resultant accelerations of $\pm .28g$ on TC-4 and $\pm .42g$ on TC-3 were experienced. Figure 5.5.9 is an envelope of VLC cg $\ddot{Y}$ PSD analyses.

Table 5.5.1 Flight Measured Vibratory Accelerations, First Longitudinal Mode Oscillation, Titan Stage 1 Burn

Launch Vehicle	Time From Lift Off (Seconds)	Steady State Acceleration (g's)	Max Oscillation g (0 - peak): VO Bus Longit.	VO Bus Lateral	VLC cg Longit.	VLC cg Lateral	Predominant Frequency (Hertz)
TC-1	242	2.77	.70	.08	no data		11.8 & 13.8
TC-2	229	2.85	.35	.03	no data		12.5
	254	3.50	.90	.19			16.0
TC-4	234	2.69	.22	.08	.44	.12	12.5
TC-3	241	3.38	.27	.08	.50	.10	14.0

NOTE: The measurement location on TC-2 is at a location on the Helios A spacecraft attachment fitting which is analogous to the Viking Orbiter bus in the Launch Vehicle/Spacecraft frame of reference.

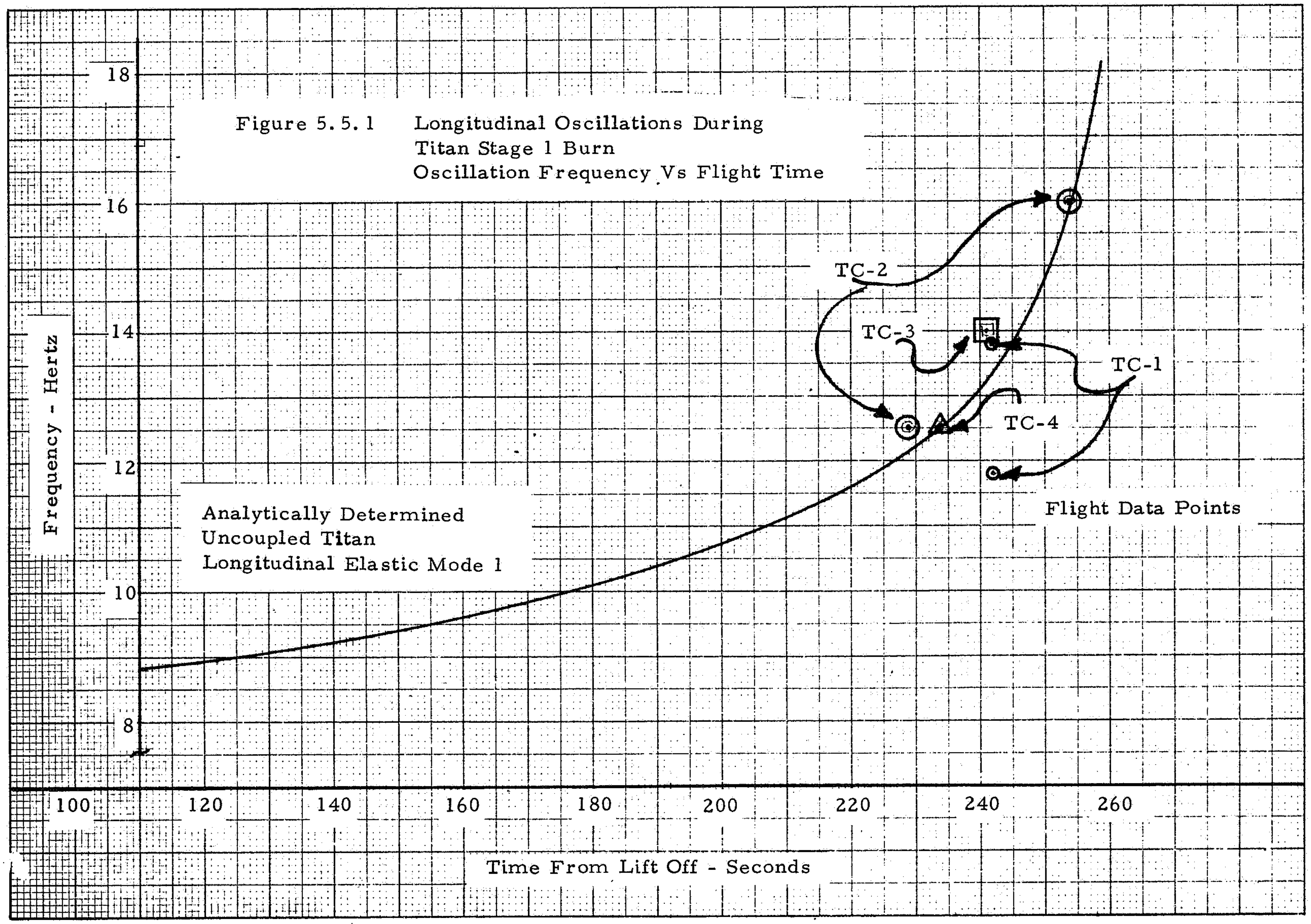


Figure 5.5.1 Longitudinal Oscillations During
Titan Stage 1 Burn
Oscillation Frequency Vs Flight Time
Analytically Determined
Uncoupled Titan
Longitudinal Elastic Mode 1
TC-2
TC-3
TC-1
TC-4
Flight Data Points
Frequency - Hertz
18
16
14
12
10
8
100
120
140
160
180
200
220
240
260
Time From Lift Off - Seconds

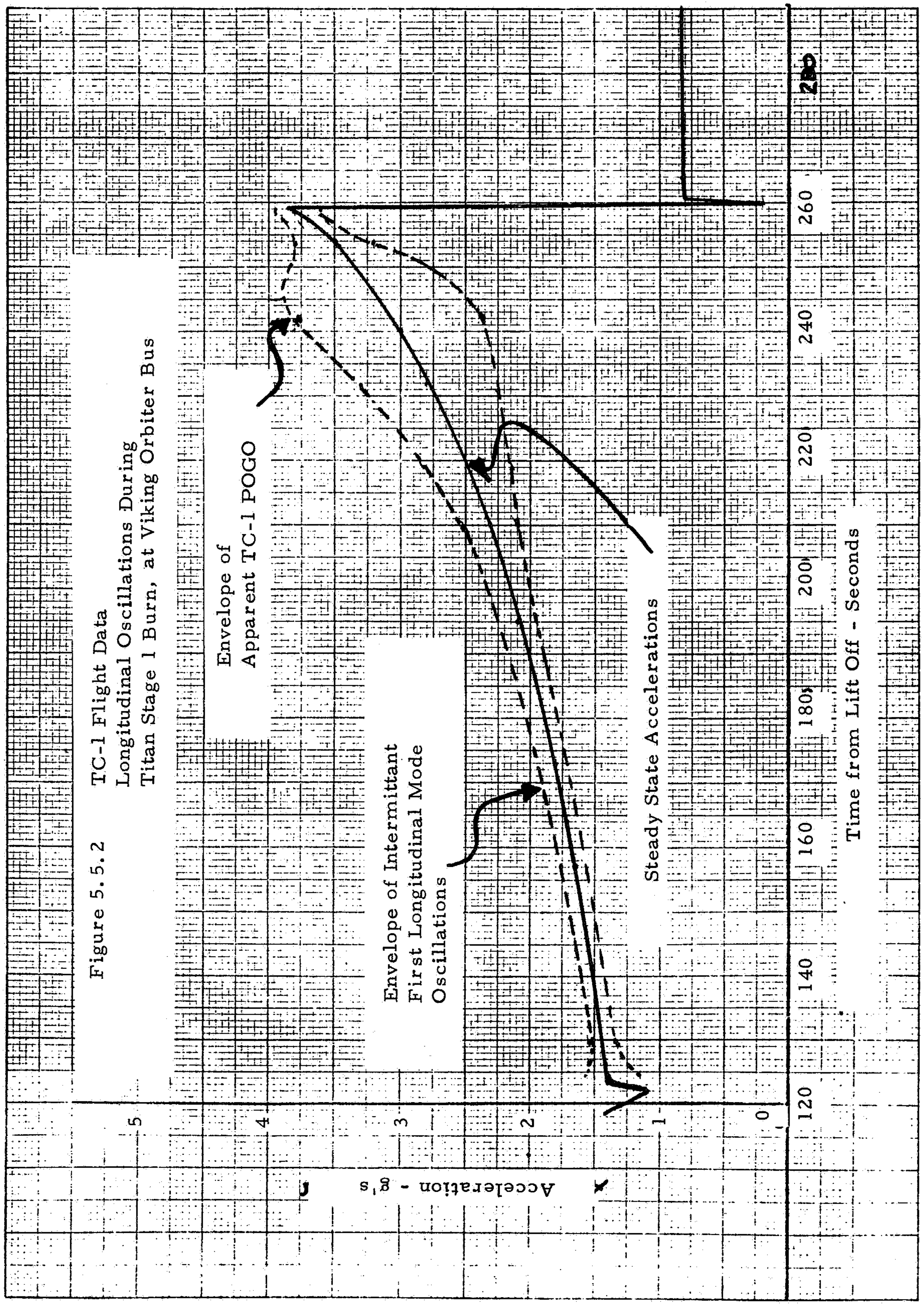


Figure 5.5.2 TC-1 Flight Data
Longitudinal Oscillations During
Titan Stage 1 Burn, at Viking Orbiter Bus

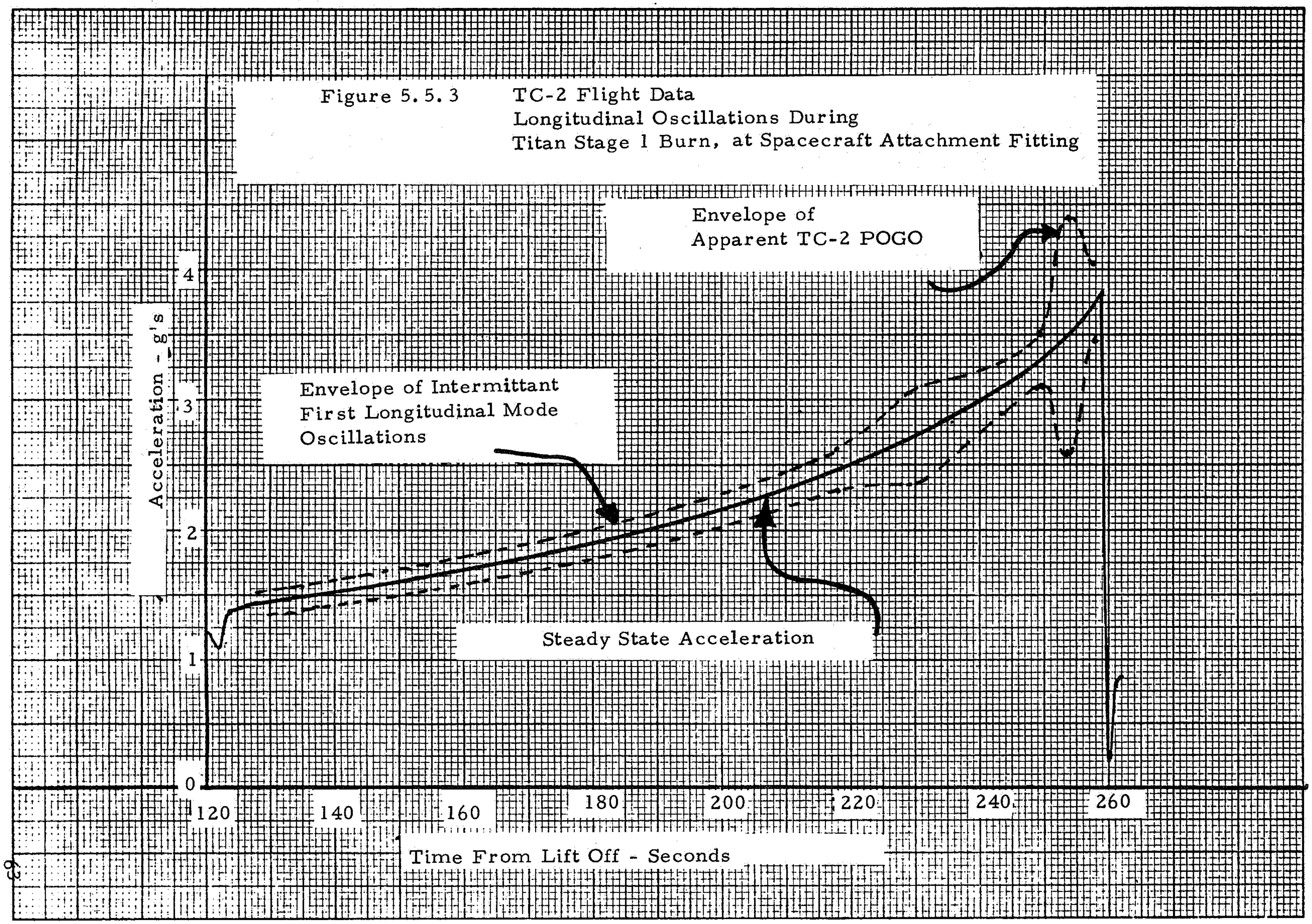


Figure 5.5.3 TC-2 Flight Data
Longitudinal Oscillations During
Titan Stage 1 Burn, at Spacecraft Attachment Fitting

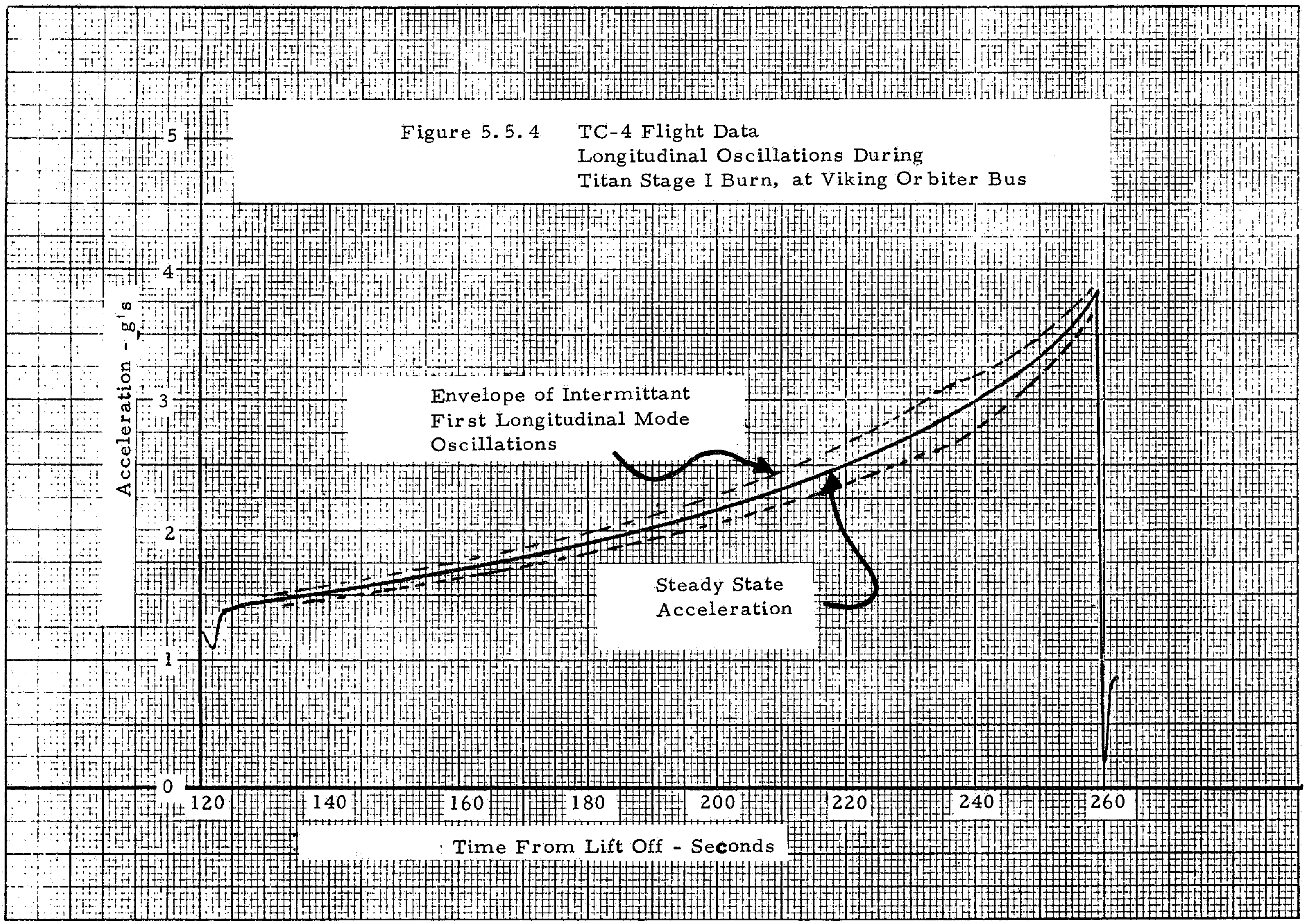


Figure 5.5.4 TC-4 Flight Data
Longitudinal Oscillations During
Titan Stage I Burn, at Viking Orbiter Bus

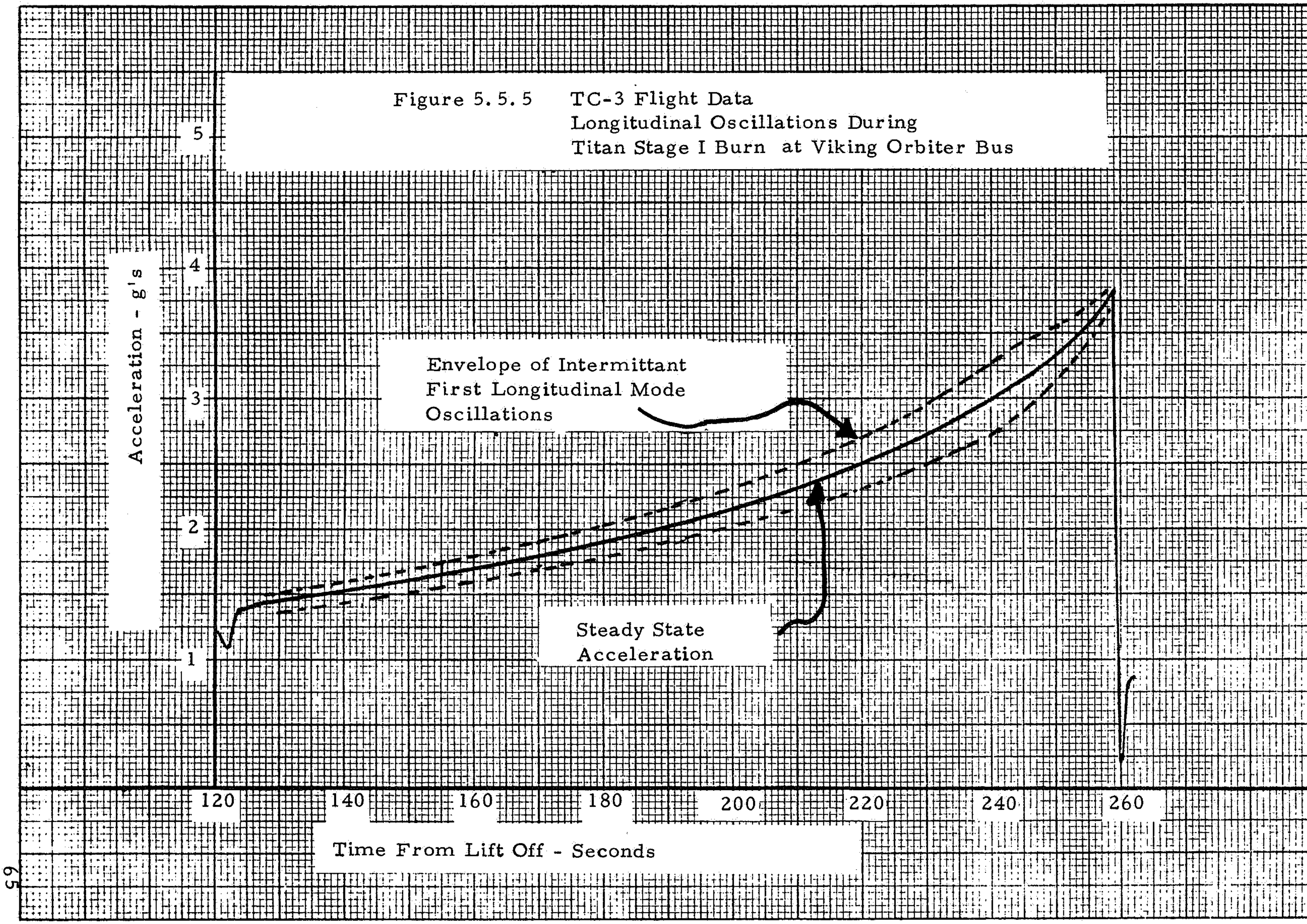


Figure 5.5.5 TC-3 Flight Data
Longitudinal Oscillations During
Titan Stage I Burn at Viking Orbiter Bus

Figure 5.5.6

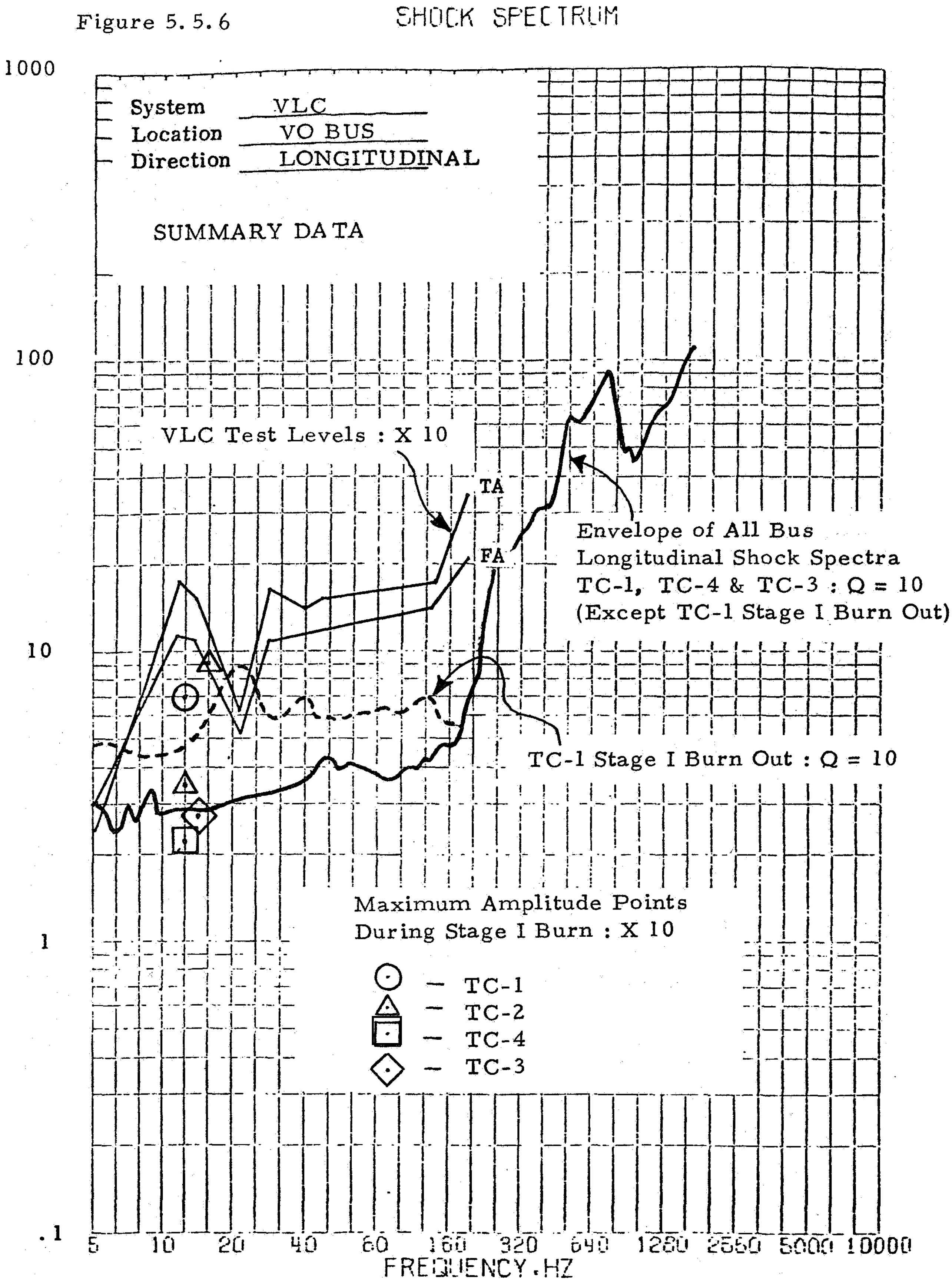
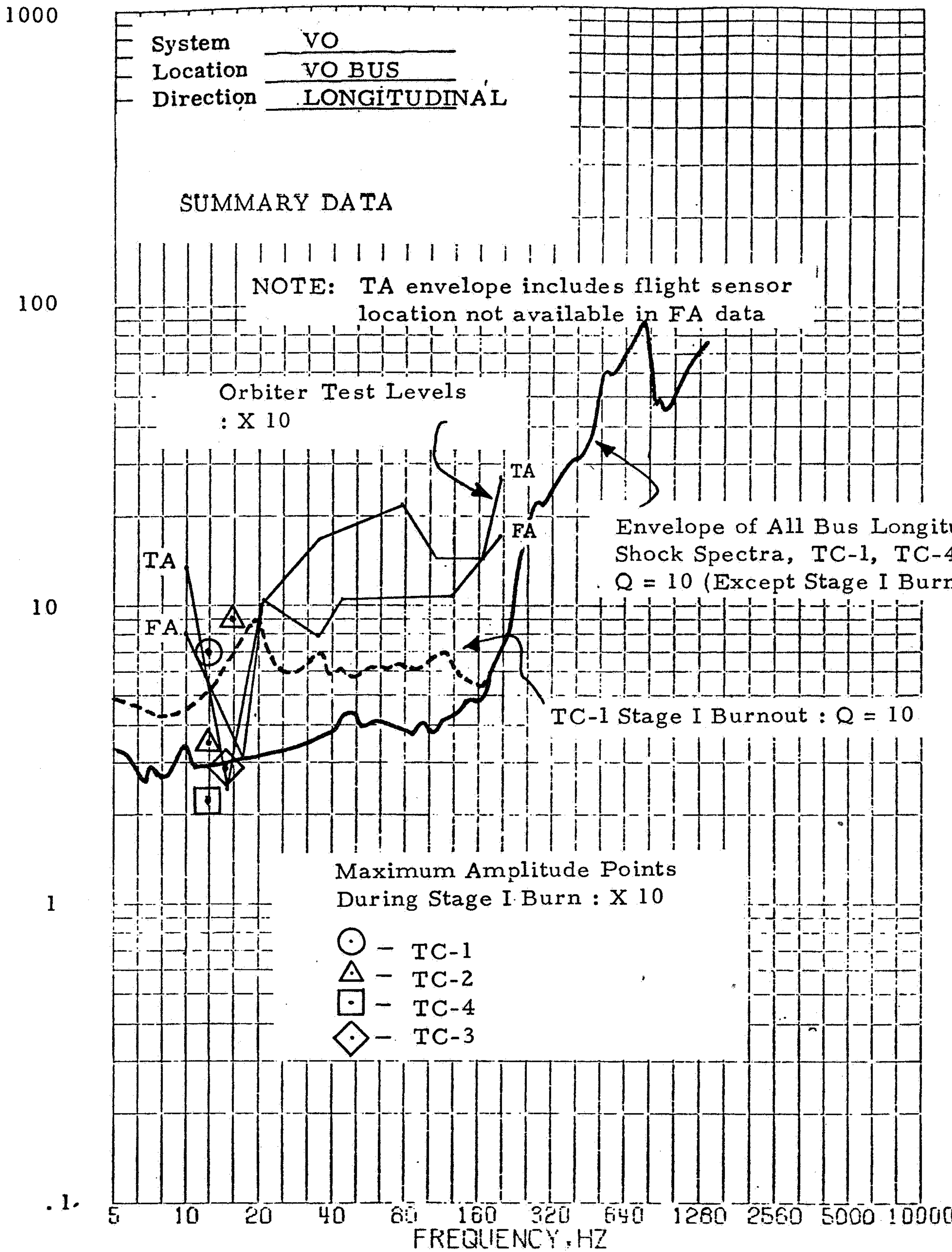

SHOCK SPECTRUM
1000
100
10
1
.1
System VLC
Location VO BUS
Direction LONGITUDINAL
SUMMARY DATA
VLC Test Levels : X 10
TA
FA
Envelope of All Bus Longitudinal Shock Spectra TC-1, TC-4 & TC-3 : Q = 10 (Except TC-1 Stage I Burn Out)
TC-1 Stage I Burn Out : Q = 10
Maximum Amplitude Points During Stage I Burn : X 10
— TC-1
— TC-2
— TC-4
— TC-3
5
10
20
40
80
160
320
640
1280
2560
5000
10000
FREQUENCY.HZ

Figure 5.5.7 SHOCK SPECTRUM



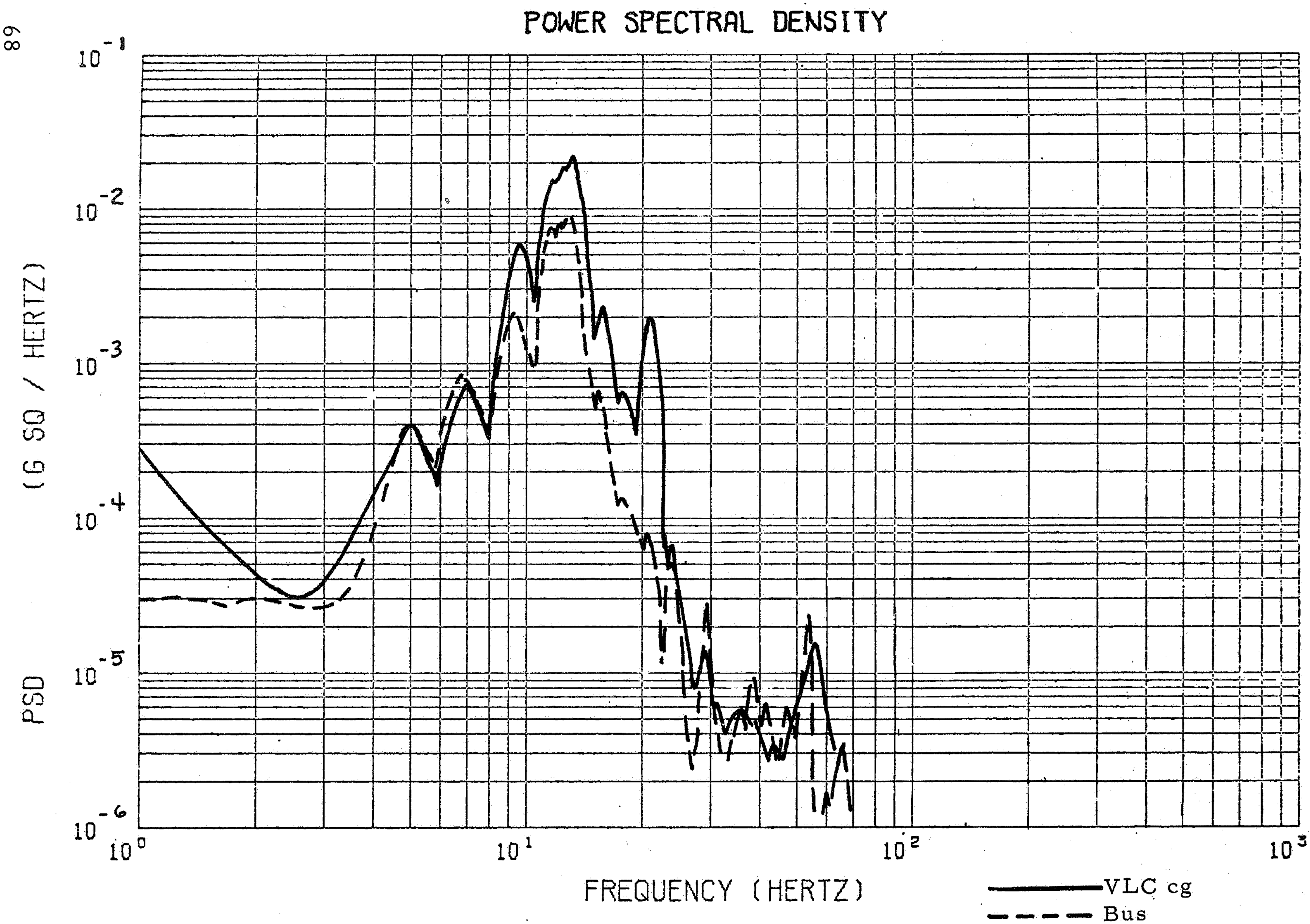


Figure 5.5.8 Envelopes of Longitudinal Oscillations During Titan Stage 1 Burn From TC-4 and TC-3

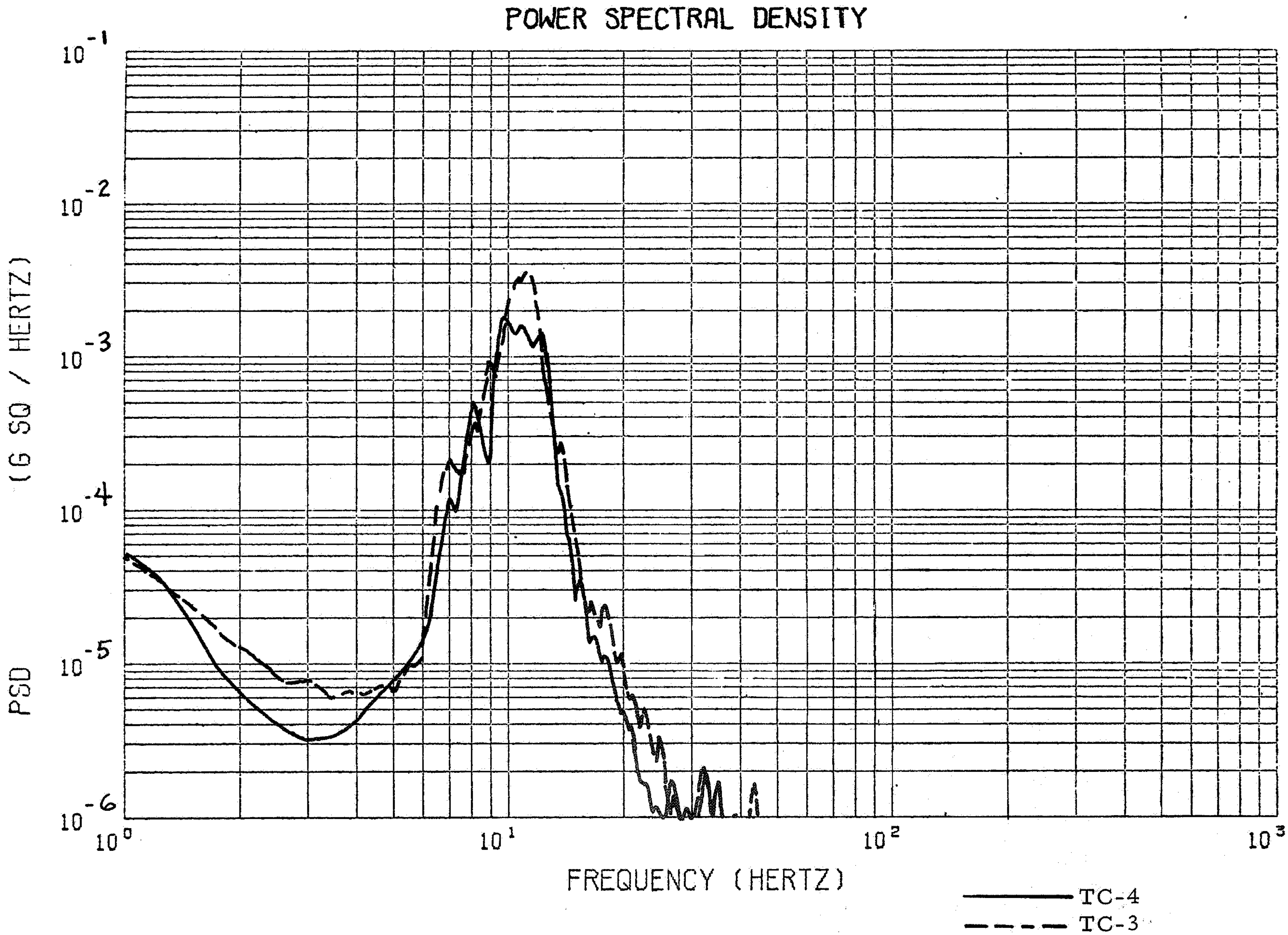


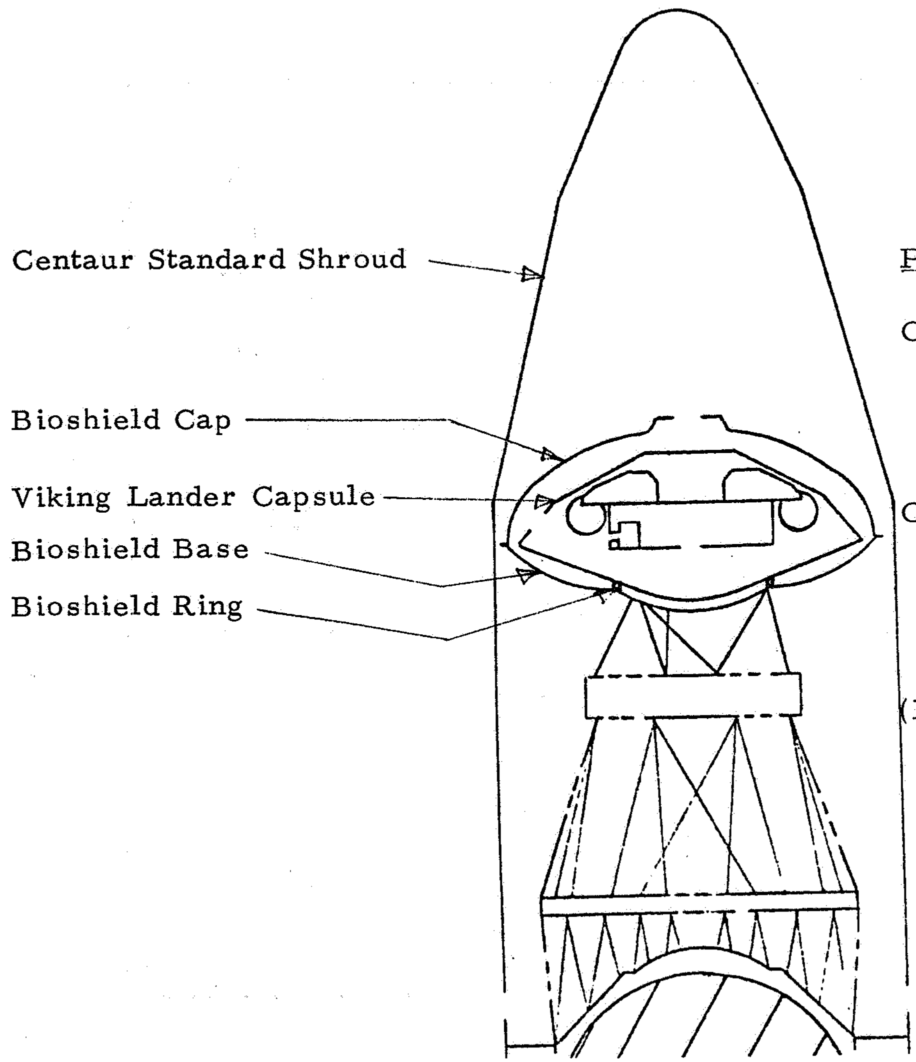
Figure 5.5.9 Envelopes of Lateral Oscillations During Centaur Burn - YDDL

5.6 Venting Pressures

There were two pressure measurements made on each of the Viking spacecraft. One measured the absolute pressure in the Centaur Standard Shroud. The other measured the differential pressure across the Viking Bioshield base. Figure 5.6.1 shows a schematic of the pressure sensor location. In the analysis of the data the sum of these two pressures was also obtained. Thus there are three pressure time histories presented in this report: the shroud pressure, the Bioshield pressure and their difference.

This pressure data is presented here for information and reference. The time rate of change of pressure is also plotted with each pressure.

The venting of the Viking Spacecraft and Centaur Standard Shroud were close to expected, the Bioshield ΔP being within the predicted bounds but closer to the lower limit prediction. The two flight systems were very close in performance.



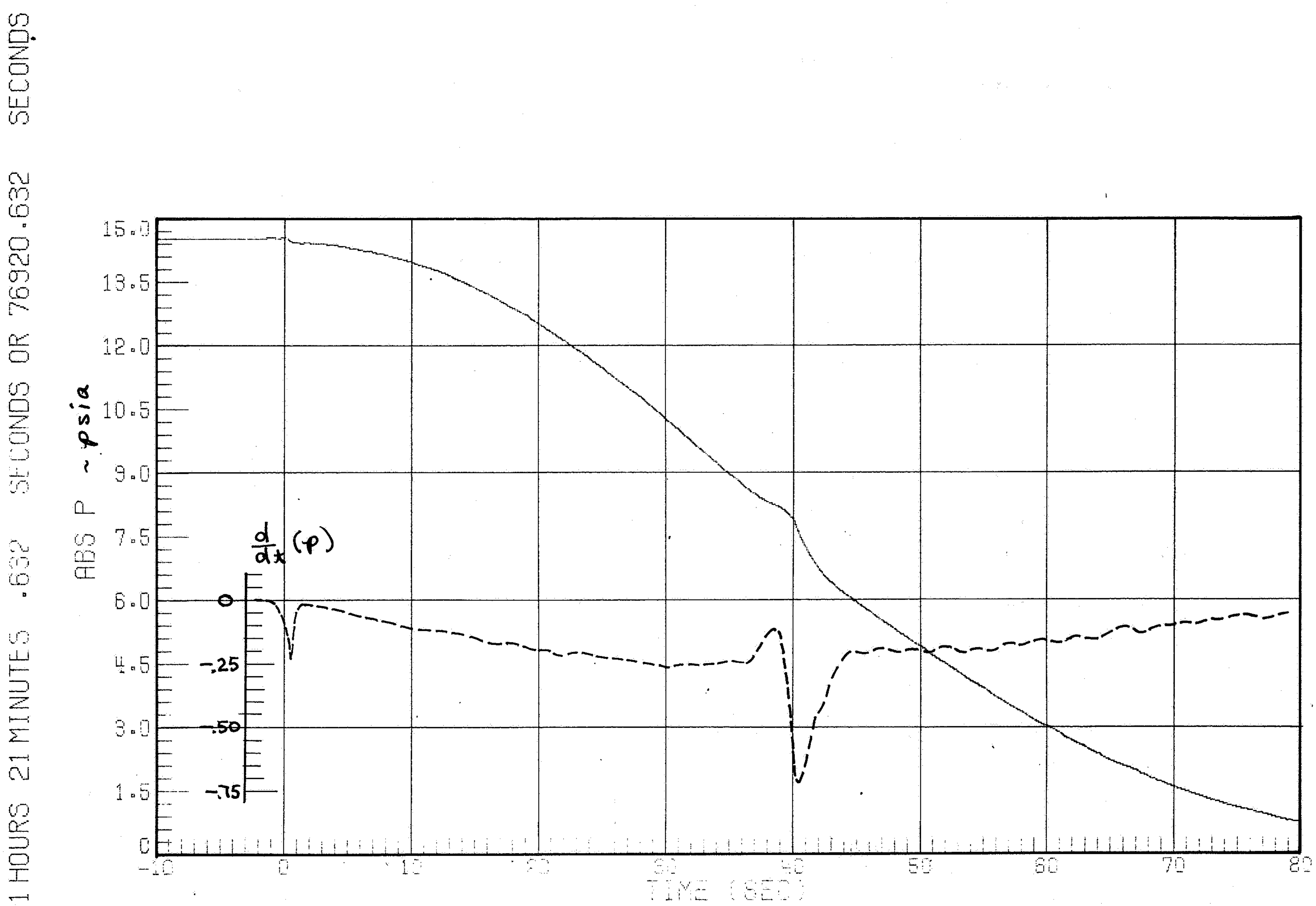
Pressure Measurements on Bioshield Ring

CY 192 P - Differential Pressure Across Bioshield
Range: -.25 to + .75 psid
IRIG VCO: No. 4
Filter Cut Off Frequency: .4 Hz

CY 193P - Pressure Inside Centaur Standard Shroud
Range: 0-16 psia
IRIG VCO No. 3
Filter Cut off Frequency 4 Hz

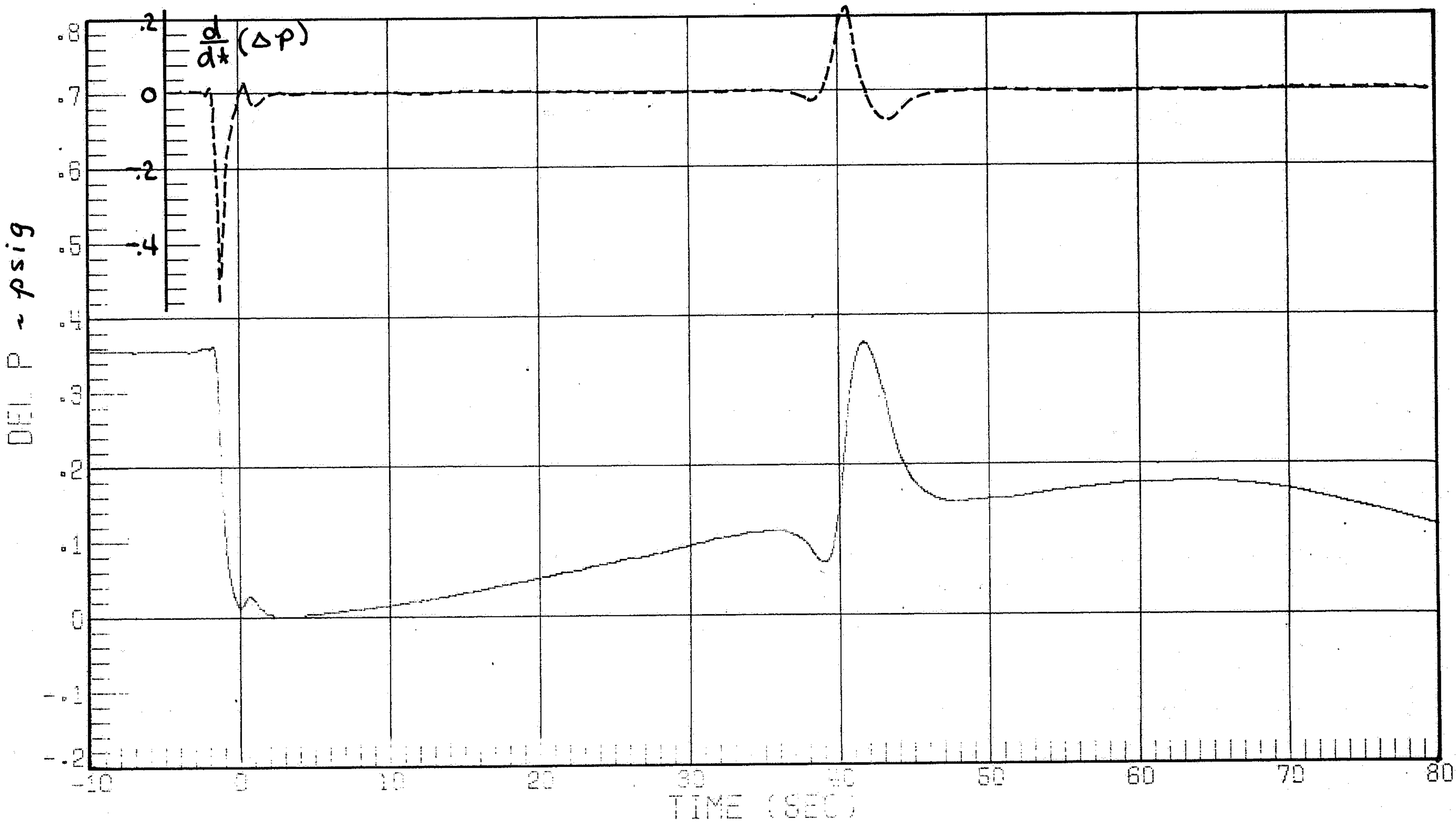
(Digitization rate in A/D conversion:
200 samples per second)

Figure 5.6.1 Description of Bioshield Pressure Measurements on Viking Spacecraft Launch Flight for both TC-4 and TC-3



VIKING A FLIGHT DATA-BIOSHIELD PRESS. -CY193P SMOOTH   **Figure 5.6.2**

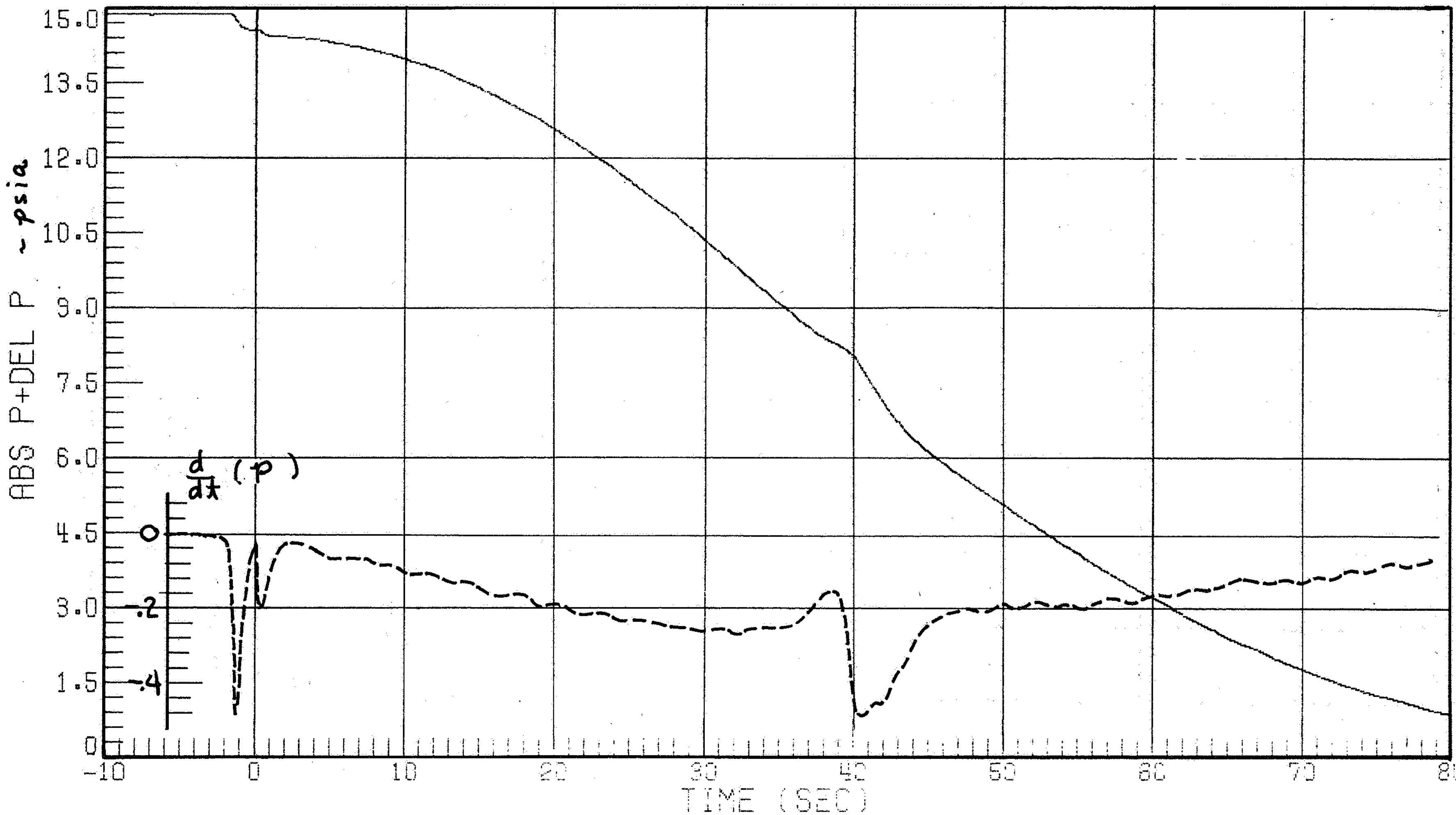
21 HOURS 21 MINUTES .632 SECONDS OR 76920.632 SECOND



VIKING A FLIGHT DATA-BIOSHIELD DEL P -CY192P SMOOTH

Figure 5.6.3

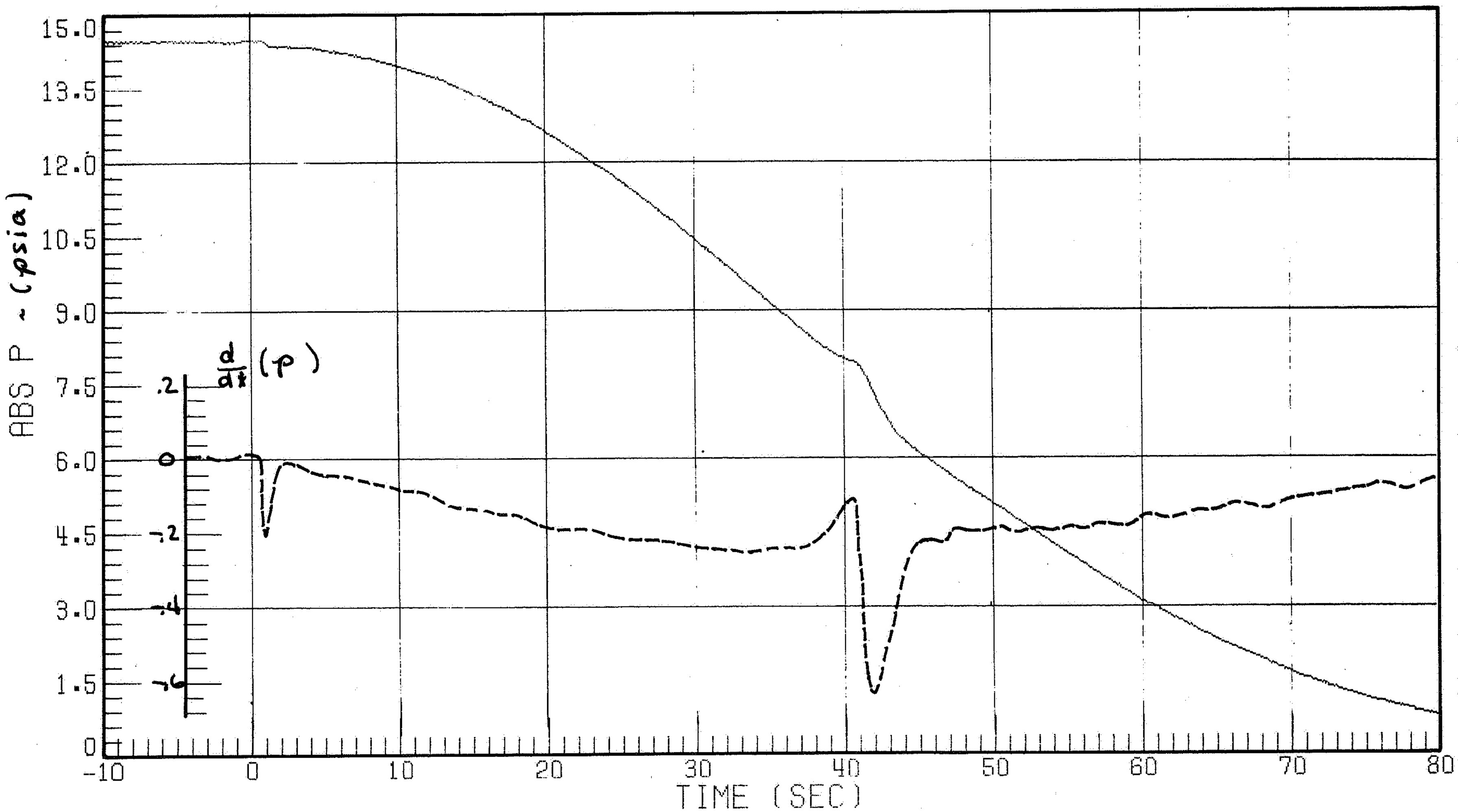
21 HOURS 21 MINUTES .632 SECONDS OR 76920.632 SECONDS



VIKING A FLIGHT DATA-BIOSHIELD (PRESS.+DEL P) SMOOTH

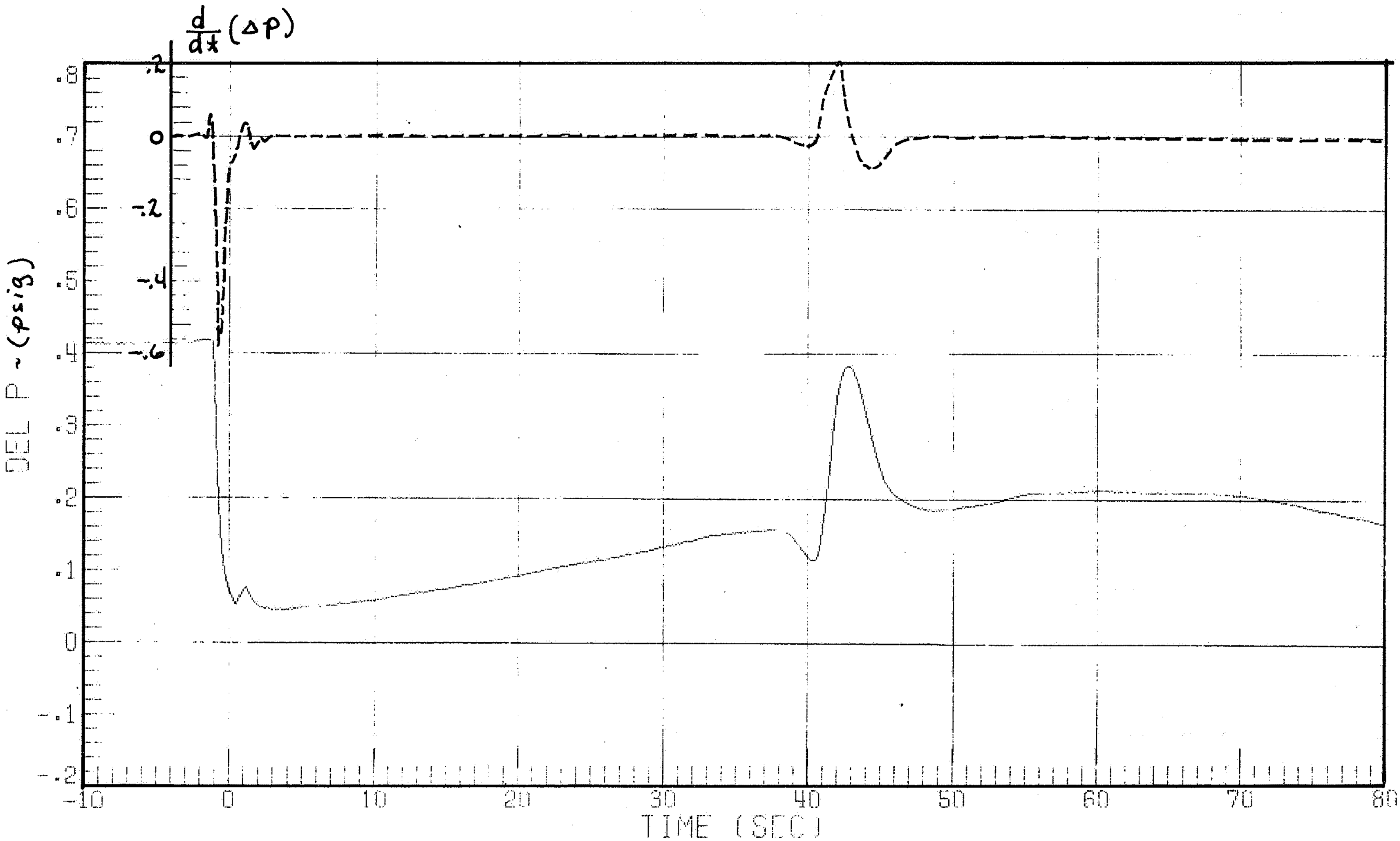
Figure 5.6.4

18 HOURS 38 MINUTES 0.000 SECONDS OR 67140.000 SECONE



VIKING B FLIGHT DATA-BIOSHIELD,PRESS. -CY193P

Figure 5.6.5

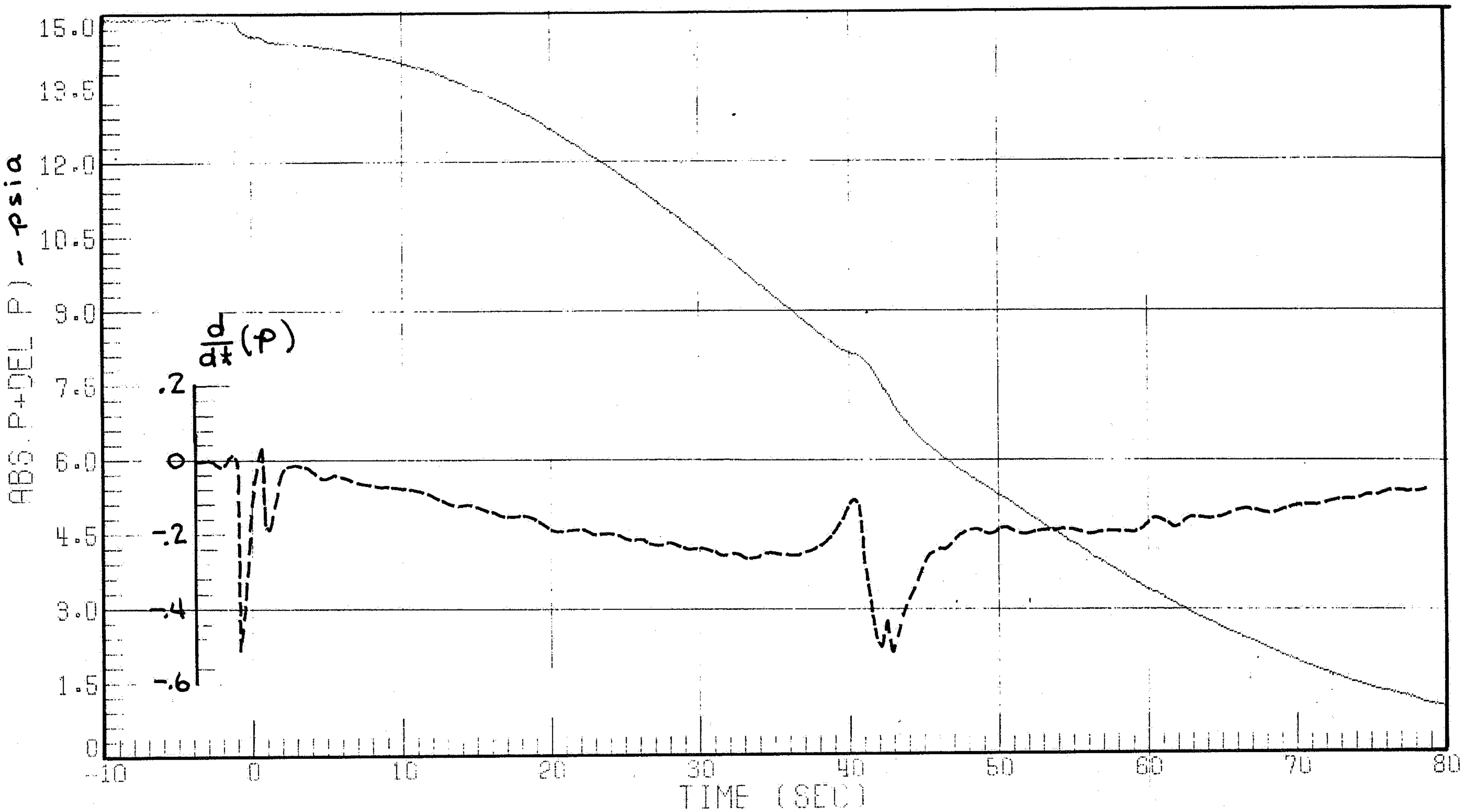


VIKING B FLIGHT DATA-BIOSHIELD DEL P -CY192P

Figure 5.6.6

18 HOURS 38 MINUTES 0.000 SECONDS OR 67140.000 SECONDS

18HOURS 38MINUTES 0.000 SECONDS OR 67140.000 SECOND



VIKING B FLIGHT DATA-BIOSHIELD (PRESS.+DEL P)

Figure 5.6.7

6. Conclusions & Recommendations

6.1 Acoustic Environment

The Viking acoustic test requirements were found to be low at both ends of the frequency spectrum and high in the center. Two factors probably caused this discrepancy. First the transmission loss through the shroud was probably underestimated hence the high values in the middle frequencies (i. e. 100-400 Hertz). This is the frequency range where shroud shell resonances would normally cause minimum transmission loss. However the Centaur Standard Shroud (CSS) with its relatively heavy internal thermal blankets will have relatively high damping in its shell modes. This added damping along with the added mass of the thermal blankets will result in higher transmission loss in this middle frequency band.

The second factor explaining the discrepancy between prediction and flight measurements is that the specification spectrum is typical in shape of the spectra with the highest overall Db. However in the Titan Centaur data studied it was found that the spectrum shape changed significantly through the flight and that an envelope of all spectra results in a relatively flat spectrum.

These four were the first flights of the Titan Centaur combination and of the Centaur Standard Shroud. Further there was not experimental determination of the transmission loss through the CSS. Consequently the prediction versus flight discrepancies are actually within the span of expectations. The trade-off which was in effect made by not performing preflight experimental determination of acoustic transmission loss through the CSS was the cost saving against the added risk of flight failures due to a possible undertest.

6.2 Vibration Environments

Random vibration levels measured on TC-1, TC-4 and TC-3 Payloads were all well below the minimum component test requirements. Also the shape of the vibration Power Spectral Density (PSD) spectra from flight were very different. Two explanations are given. First the acoustic spectra causing the random vibration were not as predicted, the vibration and acoustic flight data following the same patterns of being low by comparison in the middle frequencies. Also the flight measurements were not made at component mounting points and a direct comparison to component test levels is not valid.

The conclusion is drawn that for the majority of equipment packages on the Viking Spacecraft the random vibration levels are below the minimum test requirements (Figure 5. 2. 5) found to be necessary for adequate demonstration of reliability and workmanship.

6.3 Overpressure at SRM Ignition

Based on the acoustic measurements the overpressure has a period corresponding to a frequency in the 2 - 3 Hertz range, can also have a sharp front (i.e. like a sawtooth) and is traveling up the launch which are about 700 feet per second.

The acoustic measurements internal to the shroud do not provide a reliable quantative measure of the external pressure surge. Recommendation is made that ground based pressure measurement on an actual launching with enough measurements to define pressure variations around as well as up and down the L/V.

6.4 Shock Spectra - Mid Frequency Sine Test Comparison

Comparison of flight data with Viking Mid-Frequency Sine Sweep Testing on a shock spectrum basis with $Q = 10$, indicates that the testing was conservative by being of higher level than necessary except in the 10-25 Hertz range where the tests were notched. In theory it was not necessary to have margins at the point of notch since the structure was demonstrated at these loads by static test in a more accurate and realistic manner (for the low frequencies) than could be done by the sine sweep test.

If it is desired to make the spacecraft structures good for flight loads experienced by TC-1 and TC-2 in Stage 1 longitudinal oscillations the 1 g sine test (FA level) should be done without notching.

A proper exposition on the pros and cons of sine sweep testing of spacecraft with comparisons to alternative test methods is beyond the scope of this report. Instead two observations will be made in support of the sine test method: (1) Flight experience on Viking showed that flight levels were less than test levels. (2) Both Viking launch flights were successful with no evidence of flight problems or failure due to launch dynamic loads.

7. List of References

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3. Kachadourian, George; A Compilation of Spacecraft Loads Data from Four Titan Centaur Launch Vehicle Flights: Volume I - Acoustic Data (NASA CR-144944); Volume II - Vibration Power Spectral Density Data (NASA CR-144945); Volume III - Shock Spectra of Transients (NASA CR-144946); Volume IV - Titan Stage I and Centaur Burn Oscillation (NASA CR-144947); Volume V - Time History Plots (NASA CR-144948), May 1976.

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5. Garba, John A., Flight Data Obtained from Viking "A" During the Titan and Centaur Powered Flight. Jet Propulsion Laboratory Report 611-126, October 1975.

6. Garba, John A., Flight Data Obtained from Viking "B" During the Titan and Centaur Powered Flight, Jet Propulsion Laboratory Report No. 611-128, November 1975.

8. Nomenclature and Acronym

AFETR	Air Force Eastern Test Range
BW	Band width, frequency
CSS	Centaur Standard Shroud
Db	decibel
FA	Flight Acceptance test
GD/CA	General Dynamics/Convair Aerospace, San Diego, CA.
JPL	Jet Propulsion Laboratory, Pasadena, CA.
KSC	NASA Kennedy Space Center
MECO	Centaur Main Engine Cut Off
MES	Centaur Main Engine Start
MMC	Martin Marietta Corporation, Denver, CO.
OB	Octave Band - any frequency band where the upper band limit is twice the frequency of the lower band limit
PSD	Power Spectral Density
Q	Dynamic Pressure when used in connection with launch flight trajectories
Q	Dynamic Amplification Factor when used in connection with structural resonances and in Shock Spectrum Analyses
SPL	Sound Pressure Level
TA	Type Approval Test (i.e. qualification)
TC-1	Titan Centaur Launch Vehicle Number 1
TC-2	Titan Centaur Launch Vehicle Number 2
TC-3	Titan Centaur Launch Vehicle Number 3

TC-4	Titan Centaur Launch Vehicle Number 4
VDS	Viking Dynamic Simulator (TC-1 payload)
VLC	Viking Lander Capsule
VLCA	Viking Lander Capsule Adapter
VO	Viking Orbiter
VPO	Viking Project Office, NASA Langley Research Center
V S/C	Viking Spacecraft
V S/C A	Viking Spacecraft Adapter

NASA-Langley, 1977 CR-2645

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